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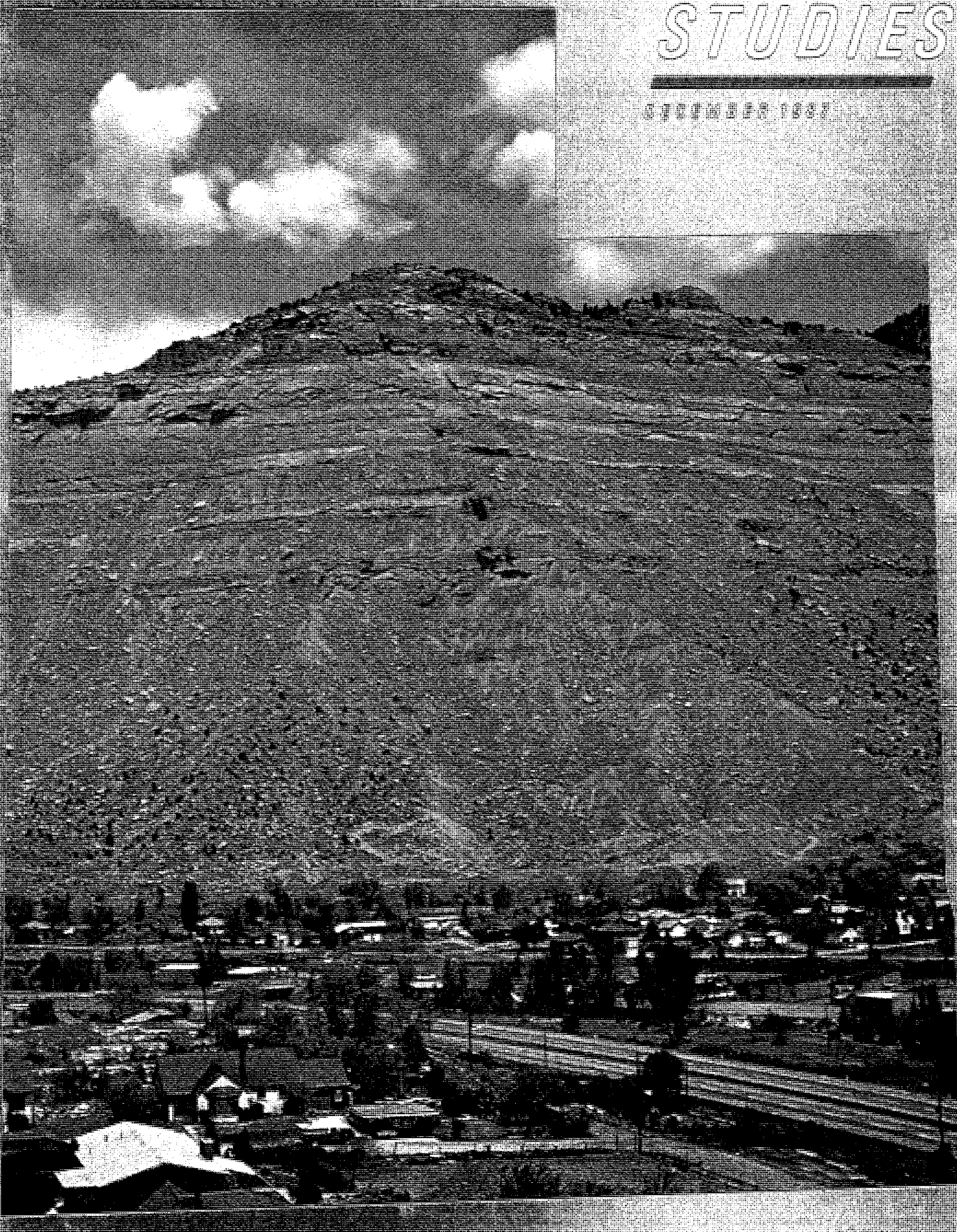

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Cover: Cretaceous coal-bearing rocks near Price, Utah

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Geology, Depositional Environments, and Coal Resources of the Helper 7½′ Quadrangle, Carbon County, Utah

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ABSTRACT

The bold escarpment of the Book Cliffs in the Helper 7½-Minute Quadrangle exposes a cross-sectional view of strata deposited in wave-dominated deltas during Late Cretaceous time and provides information regarding prodelta, foreshore, shoreface, delta-plain, and coastal-plain sedimentation. Younger Cretaceous-Tertiary strata accumulated in upper delta plain and fluvial-lacustrine environments.

Mancos Shale is the oldest unit exposed in the quadrangle and is a silty, organic-rich marine shale that is divided in the Helper Quadrangle by two deltaic sandstone tongues, the Garley Canyon and Emery Sandstone Members. Both sandstone members thin and pinch out eastward in the quadrangle. These sandstones resulted from deposition of clastic sediments that were swept eastward off the Sevier orogenic uplands into the Cretaceous Interior Seaway, whose western shoreline trended northeast–southwest in the Helper area.

The overlying Star Point Sandstone is also composed of two deltaic sandstones, the Panther and Storrs Sandstone Members, which interfinger with the Mancos Shale. The Blackhawk Formation, of economic importance in the quadrangle, contains four deltaic sandstones, the Spring Canyon, Aberdeen, Kenilworth, and Sunnyside Sandstone Members. Each is overlain by a coal-bearing mudstone interval, informally called here mudstone members 1 through 4. Rhythmic deposits of the Blackhawk Formation record numerous periods of shoreline progradation into the Cretaceous epeiric sea that gradually forced an irregular eastward retreat of the shoreline from the Helper area. Sediments were provided by orogenic activity along the Sevier thrust belt to the west. Broad, sandy, wave-dominated deltas lined the coast.

Thick coals developed directly upon the gently undulating beach ridge topography of the delta plain. Thinner coals developed on the upper delta and coastal plain. Economically important seams are the Castlegate A or Aberdeen seam, Castlegate B, Castlegate C, Kenilworth, Castlegate D, and Lower Sunnyside seams. Remaining coal reserves within the Helper Quadrangle are estimated at 250 million tons.

Outcrop and subsurface information document relationships between sandstone geometries and coal distribution and help construct a predictive exploration model useful in Cretaceous coals of the central Rockies. These porous sandstone bodies, encased in organic-rich shales, also create potential hydrocarbon reservoirs; thus, a clear understanding of deltaic sedimentation, provided by the Blackhawk and related formations in the Helper Quadrangle, could aid in predicting the occurrence of similar sandstones in the subsurface.

Prograding younger sediments of the coarse-grained Castlegate Sandstone and Price River Formations mark the termination of littoral-marine sedimentation in the Helper area, as braided and low-sinuosity streams flowed eastward off orogenic uplands. Depositional thinning of the Campanian Price River Formation indicates that uplifts associated with the San Rafael Swell began during Price River time. Varying thicknesses of fluvial-lacustrine rocks of the Maestrichtian North Horn Formation and a partial section of the lacustrine Paleocene Flagstaff Formation in the quadrangle represent sediments deposited into internally drained basins during uplift of the San Rafael Swell.

A thesis submitted to the Department of Geology, Brigham Young University, in partial fulfillment of the requirements for the degree of Master of Science, December 1984.

INTRODUCTION

Unexcelled exposures in the Book Cliffs north of Helper, Utah, provide valuable stratigraphic information regarding the geologic history of the area. The Helper Quadrangle lies on the western edge of the Book Cliffs Coal Field and has been the scene of extensive coal mining for almost 100 years because of tremendous coal reserves in the Cretaceous cliff-forming strata. Effective recovery of the remaining coal reserves necessitates a clear geologic understanding of the Helper Quadrangle.

The main objectives of this study are to document and interpret the geology of the Helper 7½′ Quadrangle in order to better understand the stratigraphic relationships of interfingering marine, littoral, and terrestrial sediments. Emphasis is placed on coal-bearing strata. A geologic map, at 1:24,000 scale (Russon in press), prepared during this study documents the surface geology of the quadrangle, and measured sections and drill holes provide additional information necessary to reconstruct a clear picture of depositional environments and facies relationships that allowed the accumulation of thick coals in the Helper Quadrangle.

LOCATION AND ACCESSIBILITY

The Helper 7½′ Quadrangle is located in Carbon County, Utah, about 4 miles north of Price, Utah (fig. 1). The northern part of the quadrangle includes an east-west-trending section of the Book Cliffs (fig. 2). U.S. 50 runs through the western part of the quadrangle, Utah 31 provides access to northern parts of the area, and Utah 157 goes through the center of the quadrangle. County roads and some jeep trails provide access to much of the remaining part of the quadrangle. Price River Coal Company owns most of the land from the Book Cliffs northward; private landholders own smaller parcels. Permission to gain access to these areas should be obtained from the owners.

METHODS

Fieldwork was done during the summer of 1983. A Jacob's staff was used to measure stratigraphic sections. Geologic contacts were mapped on aerial photographs and were later transferred to the Helper 7½′ topographic base (1:24,000). The detailed geologic map and cross sections are published in the Utah Geological and Mineral Survey Quadrangle Map Series (Russon in press). A reduced geologic map (fig. 3) illustrates the general surface geology of the quadrangle.

Data from numerous drill holes and measured sections done as part of the study, in conjunction with sections previously measured by Clark (1928), aided in constructing cross sections and isopach maps. Coal samples were collected for future analysis by the Utah Geological and Mineral Survey. Additional low-angle oblique aerial photographs were taken at low altitudes to obtain information from inaccessible areas.

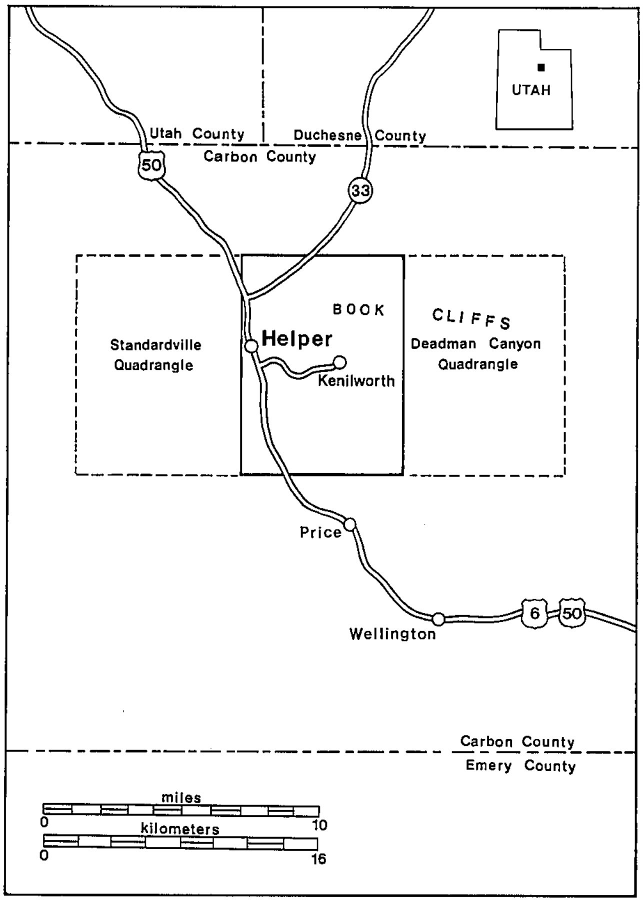


FIGURE 1.—*Index map showing the location of the Helper 7½′ Quadrangle, Carbon County, Utah.*

PREVIOUS WORKS

Many previous studies of the Helper area deal with the economic potential of the coal-bearing strata. Taff (1906) published a reconnaissance survey of the coal field that extends between Sunnyside and Castlegate. He mapped only the top and base of coal-bearing units. Clark (1928) published on the economic geology of the Castlegate, Wellington, and Sunnyside 15′ Quadrangles in Carbon County, Utah. He described the stratigraphy and structure and mapped an area that includes the Helper 7½′ Quadrangle at a scale of 1:42,240.

Spieker and Reeside (1925) and Spieker (1946) described the Mesozoic and Cenozoic rocks of the region and summarized the geologic history of central Utah. Young's studies (1955, 1957, 1966, 1976) emphasized regional stratigraphy and depositional environments of the Blackhawk Formation within the Book Cliffs. Fisher,

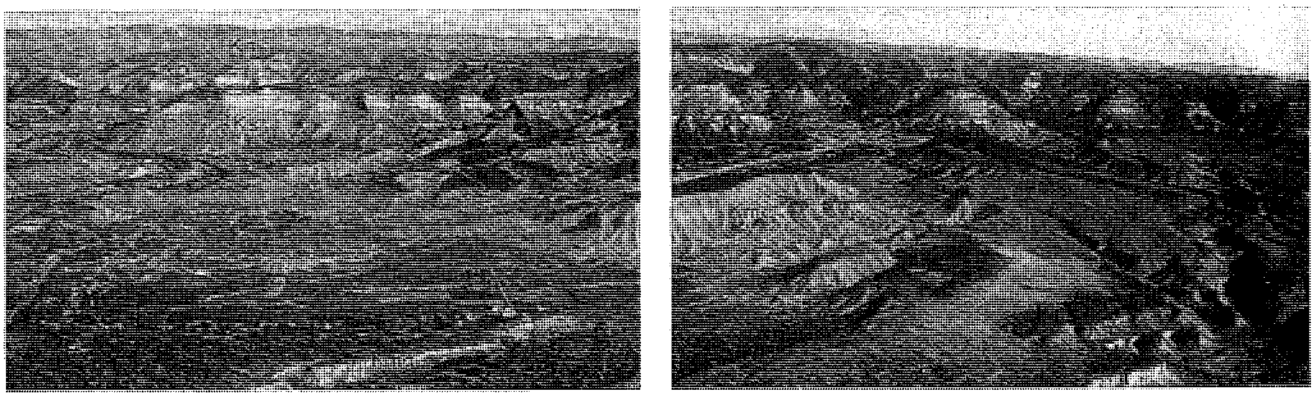


FIGURE 2.—*Aerial, northward view of the Book Cliffs in the Helper Quadrangle. The broad valley is formed by Mancos Shale, and dissected pediments are prominent below the Book Cliffs in the right part of the photograph. Labels are explained on fig. 3.*

Erdman, and Reeside (1960) studied the Cretaceous and Tertiary rocks of Carbon County.

Several individuals have concentrated on single units. Van De Graaff (1972) described the fluvial Castlegate Sandstone, and Howard (1966a, 1966b, 1966c) studied the Panther Sandstone Member of the Star Point Sandstone. Balsley (1982) published a regional study of rocks and depositional environments of the Blackhawk Formation.

Doelling (1972) and Osterwald and others (1981) have all made important studies of the stratigraphy and coal quality of the Helper Quadrangle and nearby areas. Carroll (1987), Hansen (in press), and Jensen (in press) are currently preparing geologic maps and reports of the Standardville, Jump Creek, and Fairview Quadrangles, respectively, directly west of the Helper Quadrangle. Nethercott (1986) and Anderson (1978) mapped and studied the geology of the Deadman Canyon and Pine Canyon Quadrangles directly east of the Helper Quadrangle.

STRATIGRAPHY AND DEPOSITIONAL ENVIRONMENTS

GENERAL STATEMENT

Surface units within the Helper 7½′ Quadrangle range from Late Cretaceous to Early Tertiary in age (figs. 3 and 4). The upper part of the Cretaceous Mancos Shale forms a broad slope at the base of cliffs held up by overlying units. Two sandstone members of the Mancos Shale, the Emery and Garley Canyon Sandstones, interrupt the shale slopes. Sandstone tongues of the Cretaceous Star Point Sandstone interfinger with the upper part of the Mancos Shale and thin eastward. Individual tongues of the Mancos Shale were mapped and identified by numbers 1–19 (fig. 3) to correspond with equivalent shale tongues in the Standardville Quadrangle to the west (Carroll 1987). Numerous sandstone tongues in the Standardville Quadrangle to the west pinch out eastwardly before reaching the Helper Quadrangle; thus, more divisions were mappable in the Standardville Quadrangle.

Coal-bearing Cretaceous Blackhawk Formation overlies the Star Point Sandstone. Members of the formation that have been mapped include the Spring Canyon Sandstone, Aberdeen Sandstone, Kenilworth Sandstone, and Sunnyside Sandstone Members. Each of these sandstone members is overlain by a mudstone unit, herein designated as mudstones 1 through 4, which were mapped separately. Six major coal seams occur within the Blackhawk Formation; several rest directly on sandstone members, and others occur within the mudstone members.

Coarse, complexly lenticular Castlegate Sandstone lies unconformably on the Blackhawk Formation and forms one of the major cliffs of the region. Similar, but thinner, sandstone units alternate with shale and siltstone to form the characteristic ledges and slopes of the overlying Cretaceous Price River Formation. The Price River Formation is overlain gradationally by the Late Cretaceous–Tertiary North Horn Formation. A resistant cap of Paleocene Flagstaff Limestone is the uppermost Tertiary unit preserved in the area.

Quaternary deposits in the Helper Quadrangle consist of pediment gravels, loess, and alluvium. Pediment gravel blankets much of the lower half of the quadrangle, and locally a thin layer of loess veneers the pediment and gravel surface. Talus obscures the steep slopes below the cliffs of the Blackhawk Formation in limited areas, and slope wash elsewhere commonly coats Mancos slopes. Alluvium is generally present along stream channels where gradients allow accumulation.

Facies

Measured sections document consistent recurrences of four distinct lithologies (figs. 5 and 6) within the littoral-marine sandstone tongues of the Garley and Emery

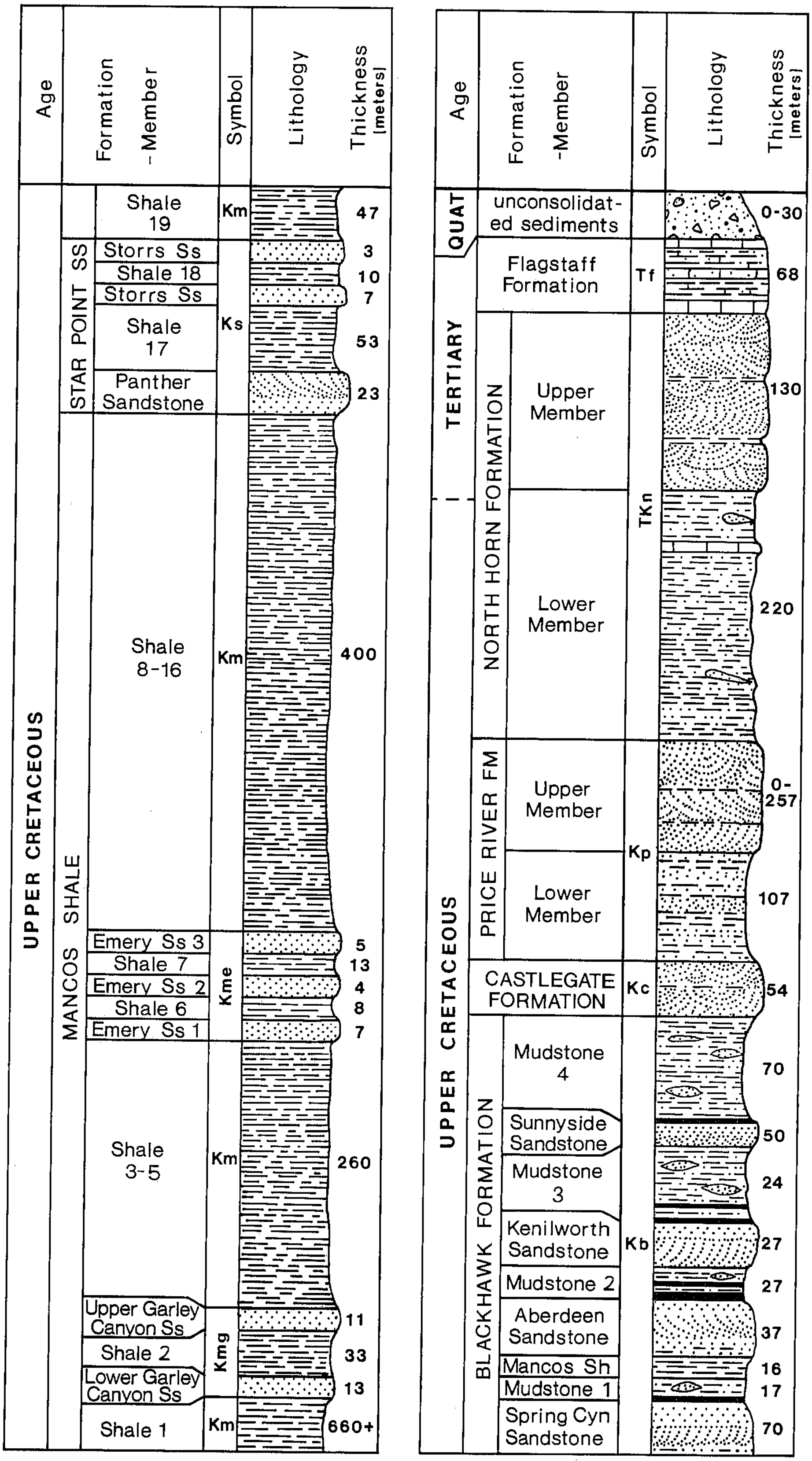


FIGURE 3.—*Generalized stratigraphic section of units exposed in the Helper Quadrangle.*

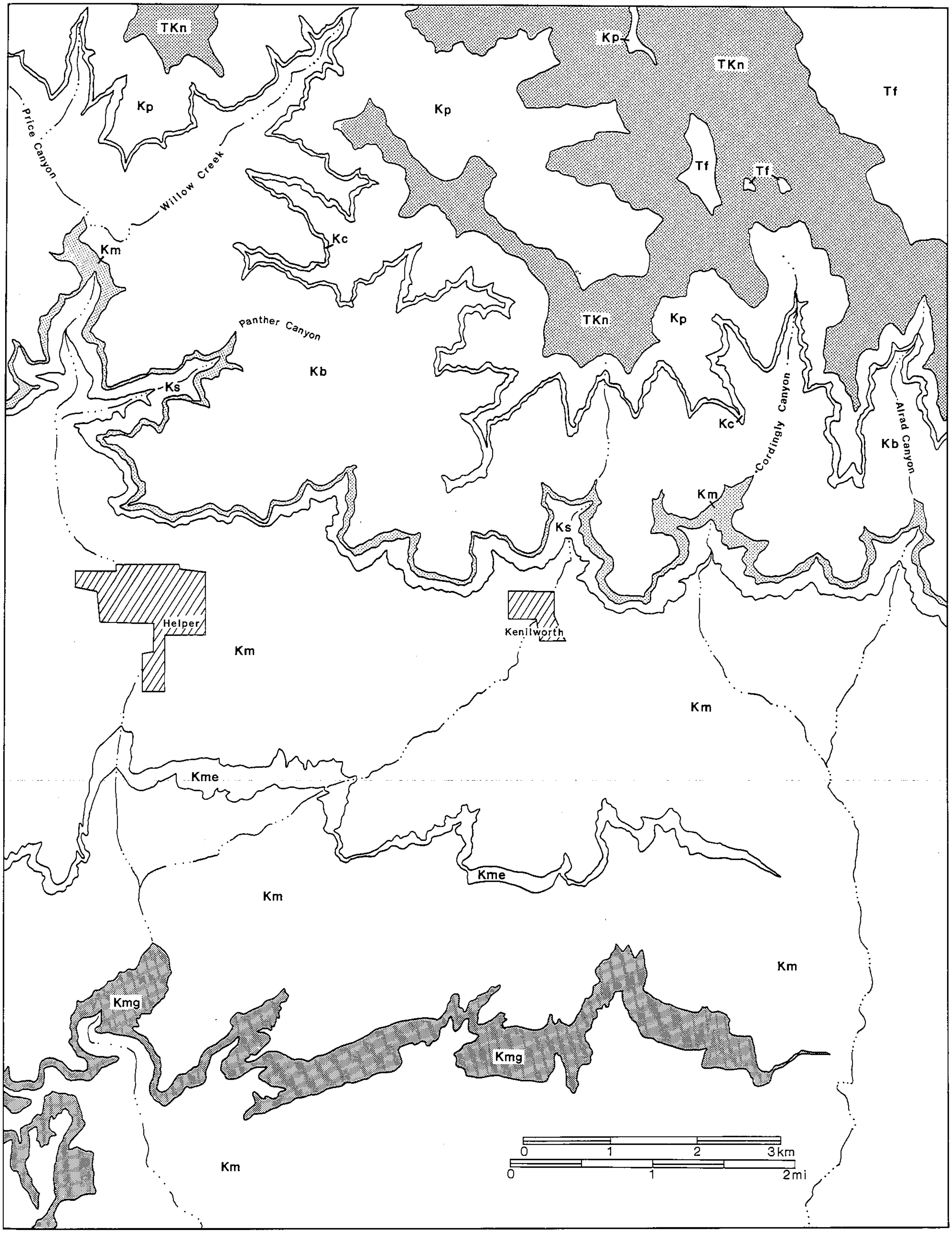


FIGURE 4.—*Simplified bedrock geologic map of the Helper Quadrangle (key to formation names on fig. 3).*

Members and Star Point and Blackhawk Formations. Each of these sandstones has distinctive characteristics, but all are also similar. These sandstones had comparable origins, and the four dominant lithologies resulted from deposition within different regimes of repeated depositional settings. This section summarizes patterns and forms a basis for discussions of these sandstones. Infor mation from Balsley (1982) provided a helpful background for discussing lithologies of the formations in the quadrangle.

The lowest lithologic unit in each sandstone, termed facies I, seems to be the most widespread of the four major facies. Rocks of this facies form the lower part of almost every littoral-marine sandstone tongue in the quadrangle (fig. 6). Thickness is highly variable, however, ranging from less than 1 m (3 ft) to over 30 m (100 ft) from member to member.

Facies I marks a transition from deposition of mud to coarser sediments. Interbedded siltstones and sandstones make up the interval; each interbed ranges from 10 cm (4 in) to 1 m (3 ft) thick. The lowermost beds grade from shale to siltstone and coarsen upward. The top of each interbedded unit, usually a very fine-grained quartz sandstone, has a sharp contact with the overlying siltstone of the next interbed of siltstone to sandstone.

Internal structures within facies I include current ripple and sole marks, very thin, planar-laminated bedding, and intensive bioturbation. The ripples are about 1.2 cm (0.5 in) high and are usually sharp crested. General current direction was to the southeast. Bedding planes are often delineated by organic matter, mostly woody, carbonaceous fragments. Abundant trace fossils consist of *Ophiomorpha*, *Asterosoma*, and *Helminthoida* a (Balsley 1982, Howard 1966c).

Siltstone units weather light gray, and sandstone units weather pale yellow orange within this transitional zone. The softer siltstones erode easily, making the sandstones appear riblike.

Beds of facies I were deposited near the sand-mud transition line between the shoreline and the basin. The facies indicates the basinward limit of sand transportation and resulted from vertical settling of sediments carried by

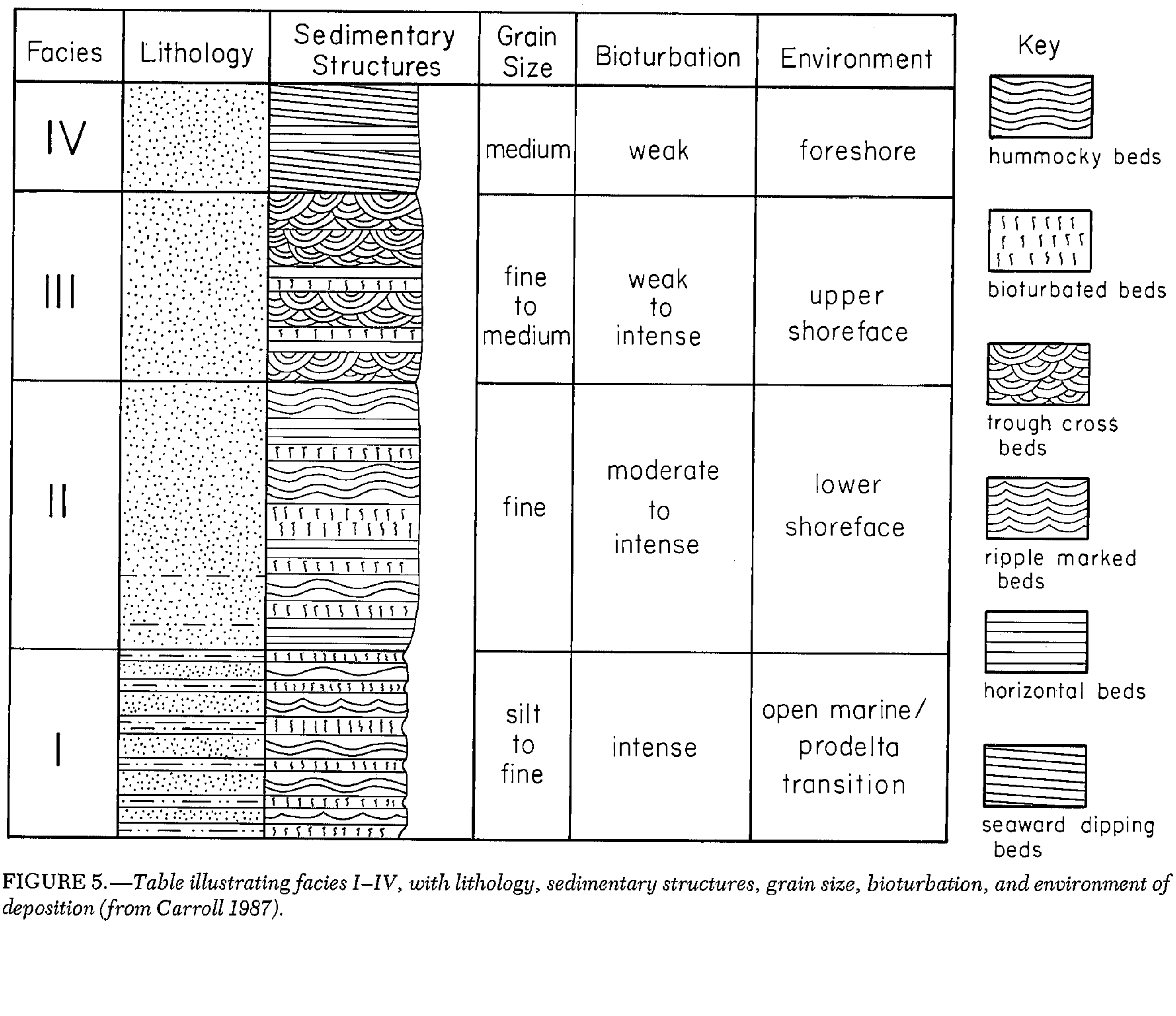


FIGURE 5.—*Table illustrating facies I–IV, with lithology, sedimentary structures, grain size, bioturbation, and environment of deposition (from Carroll 1987).*

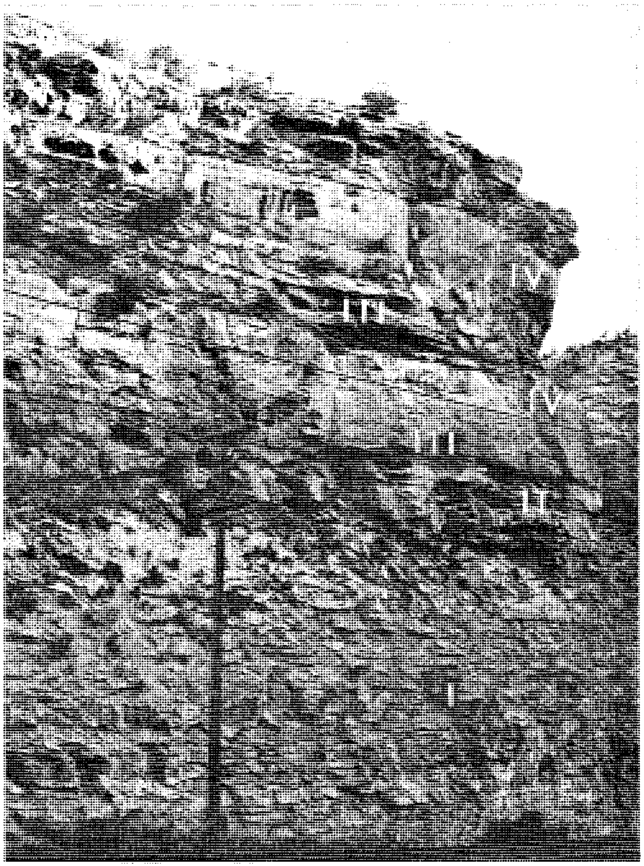


FIGURE 6.—*Outcrop of Spring Canyon member showing development of facies I–IV beds, section 1, T. 13 S, R. 9 E.*

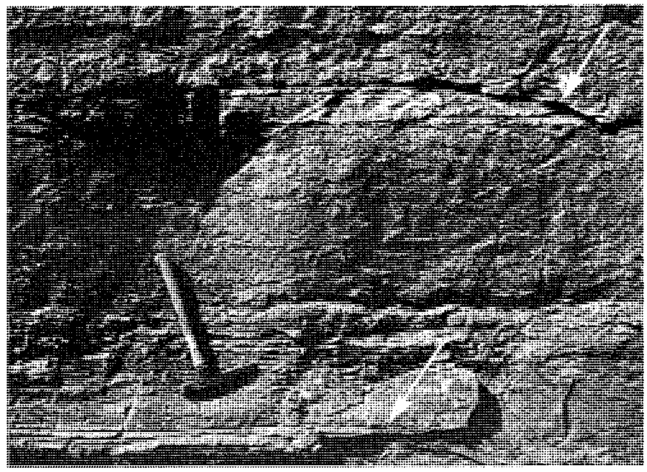


FIGURE 7.—*Closeup view of hummocky stratification (arrows) and bioturbation characteristic of facies II beds, NW, NW, NW, section 1, T. 13 S, R. 9 E.*

storm waves or turbidity currents. Facies I beds correspond to the transition zone discussed by Balsley (1982) situated between lower shoreface and prodelta environments.

Facies II gradationally overlies facies I and is composed of thin to medium beds (15–20 cm thick) of calcareous, fine-grained, quartz sandstone. This facies ranges from 3 to 21 m (10–70 ft) thick in various sandstone tongues (fig. 7). It is widespread and is consistently underlain by facies I. Thin, horizontal laminations form most of the unit, and hummocky beds often interrupt the flat layers, like those discussed by Swift et al. (1983, p. 1297). Wave ripples may occur on the surface of these sandstones. Facies II is heavily bioturbated and contains abundant trace fossils, which include *Ophiomorpha, Thalassinoides, Asterosoma, Teichichnus, Chondrites, Gyrochorte, Terrebellina*, and annelid worm burrows (Balsley 1982, Howard 1972, Nethercott 1986). This yellowish gray unit appears massive from a distance and often makes up the bulk of a sandstone member.

Beds of facies II were deposited in the lower shoreface environment. Suspended, fine-grained sand settled to form horizontally laminated beds during calm periods. Storm waves scoured and reworked these layers and formed the hummocky bedding characteristic of the facies.

Subtle differences separate facies III from underlying facies II. Facies III beds are medium-grained quartz sandstones, but may include minor percentages (up to 5%) of black chert and feldspar. Carbonaceous particles may also be present. The overall thickness of facies III in various tongues in Mancos to Blackhawk Formations ranges from 1.5 to 7 m (5–23 ft). Trough cross-bedded laminations dominate this facies. Planar sets of cross-beds, from 8 to 30 cm (3–12 in) high and 30 to 60 cm (1–2 ft) long, truncate underlying layers (fig. 8). Current directions indicated by the cross-bedding is to the southwest. The lower contact of the beds is gradational and the upper contact is usually sharp. This facies is intensely bioturbated, and commonly present are *Ophiomorpha* and cylindrical burrow structures. The weathered, pock-marked sandstones often resemble Swiss cheese. This facies need not be underlain by facies I or II. It is occasionally the basal member of a sandstone tongue that may overlie other lithologies. Facies III beds accumulated in the high-energy environment of the upper shoreface. Longshore currents and breaking waves controlled deposition in this zone, which lies between mean sea level and water about 7 m deep (Klein 1974).

Facies IV contains fine- to medium-grained sandstones that are peppered with minor amounts of black chert, feldspar, and carbonaceous flecks. This upper facies generally has a striking white cap, or light gray coloration, which may extend down through facies III (fig. 8). Often this white cap may be mappable laterally for miles. Some authors have proposed that these white caps formed where swamp waters leached the sediments, for the light

FIGURE 8.—*Closeup view of trough cross-bedded beds of facies III and seaward-dipping beds of facies IV, NW, NW, NW, section 1, T. 13 S, R. 9 E.*

sandstone is frequently directly overlain by coal. Balsley (1982, p. 74–75) proposed that the white cap is a depositional phenomenon produced because iron-bearing dolomite was not deposited due to the winnowing action of waves along the beach, therefore causing weathered exposures to lack the coloration of underlying sandstones. Drill data, however, indicate that white caps exist in the subsurface, suggesting that swamp-water leaching is the more likely cause of the discoloration. Several origins for white-cap development are likely, however, because white-capped beds occur irregularly in facies III of Star Point and Blackhawk Sandstones and, occasionally, in younger sandstones above the Blackhawk Formation as well.

Facies IV ranges from 1 to 2 m thick within sandstone tongues of the quadrangle. It consists of gently inclined, tabular bedded sandstone sets, 10 to 30 cm thick. These sets dip 2° to 6° relative to surrounding strata. These beds dip in a general south to southwest direction. An undulating surface on top of sandstones of facies IV is sometimes visible when viewed in the direction of dip of the sandstone sets (fig. 9). This rolling surface is best observed, however, in mines wherein thick coal has been stripped off the sandstone floor. Contact of facies IV beds with

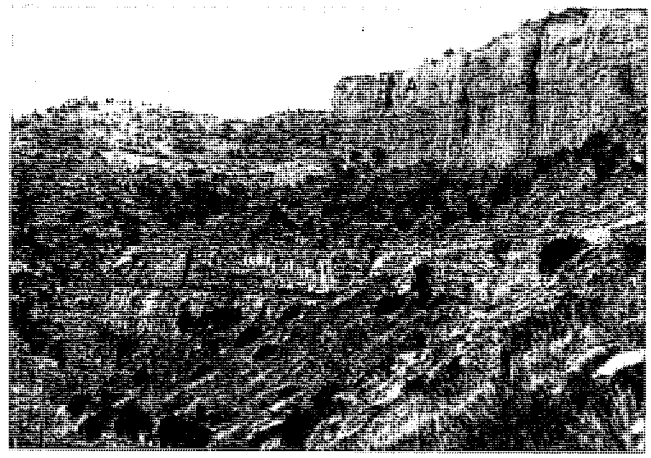


FIGURE 9.—*View southeastward in Price Canyon (NW, NW, section 1, T. 13 S, R. 9 E) of Spring Canyon (Sc) and Aberdeen (A) Members. Arrows point to seaward-dipping accretionary beds (facies IV) in two Spring Canyon tongues. Note undulating top surface of the Spring Canyon Member. Mudstone members with thick coal here overlie each sandstone.*

underlying beds of facies III is sharp, as is its top boundary. Bioturbation is minimal, but the upper surface may be rooted. Coal commonly rests directly upon facies IV rocks.

Facies IV beds of the beach formed as accretionary sheets along the sloping, sandy foreshore, where swash and backwash currents controlled sedimentation (Harms 1979). Successive accretion of the foreshore sands created the rolling topography of beach ridges on a strand plain (fig. 10).

CRETACEOUS SYSTEM

Mancos Shale

The Mancos Shale is the principle exposed bedrock of the south half of the Helper Quadrangle (figs. 3 and 4). Shale slopes are interrupted occasionally by eastward-thinning sandstone tongues that form low ledges and cliffs. Only upper beds of Mancos Shale crop out within the quadrangle, and much of the formation is veneered with pediment gravels, alluvium, and talus slopes. Mancos Shale underlies the low valley in which Price and Helper, and much of the adjacent farmlands, are located. Mancos Shale forms badland-type topography at the foot of the Book Cliffs, and steep slopes where overlain by resistant sandstones.

Precipitation erodes deep gullies in the shale because of the impervious nature of the formation. In their nearly vertical walls, deep washes expose nodular, massive mudstones and claystones characteristic of the formation. Fresh exposures are medium to bluish gray, and slope-

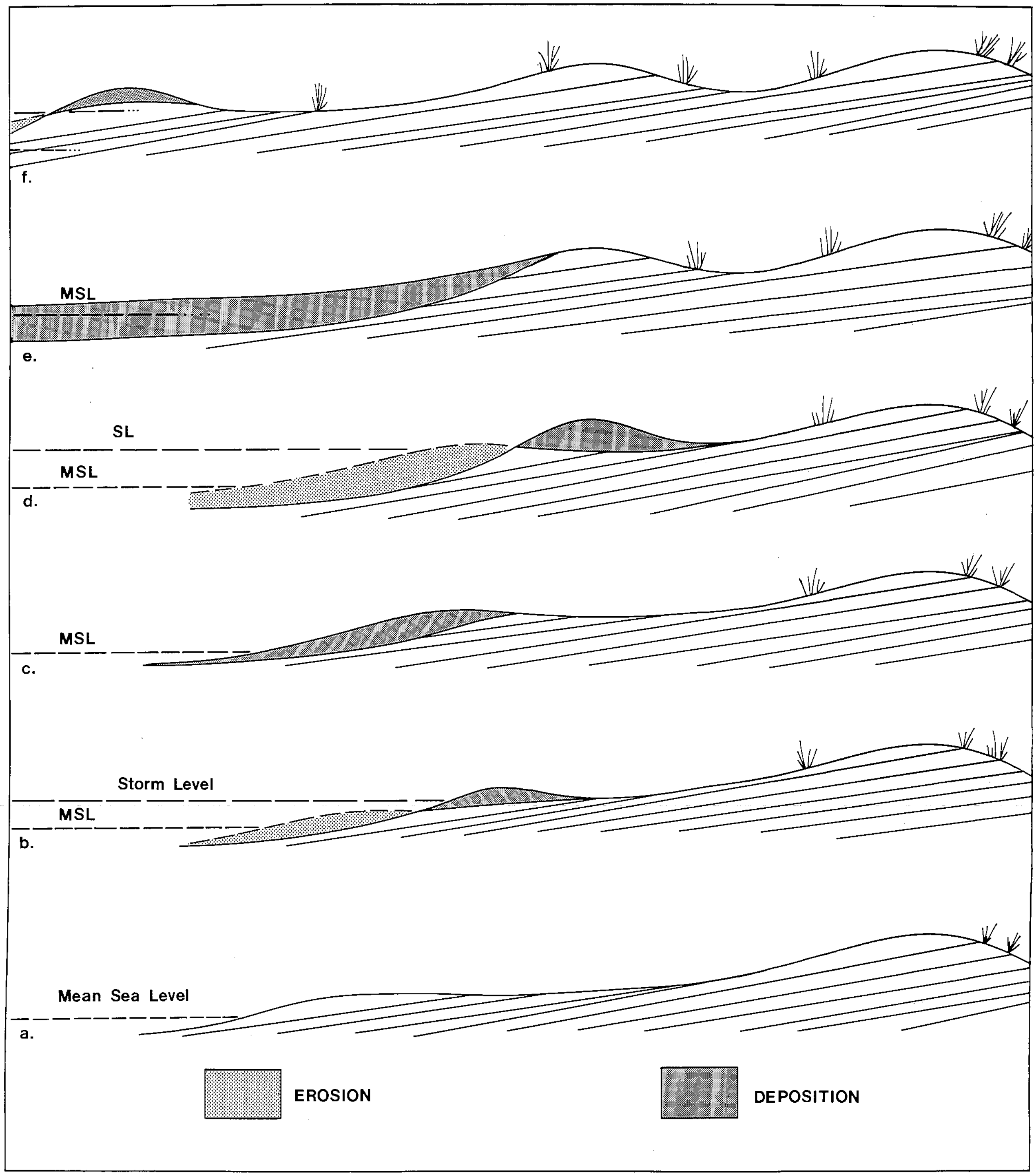


FIGURE 10.—*Model showing process of beach ridge growth (facies IV) by erosion and deposition during calm and stormy periods. Figure a represents a cross-sectional view of a beach at the time of normal sea level. During a storm, portions of the beach are eroded and redeposited, as shown in b. During calm periods, deposition occurs higher on the beach as in figure c. In d, a storm again erodes the upper beach and deposits sand farther seaward. E and f illustrate repetitions of deposition and erosion that result in successive accretions of sandy sheets along the shoreline (modified after Psuty 1967).*

wash or lag-coated exposures are brownish gray to olive gray.

The Mancos Shale in east central Utah is nearly 1500 m (5000 ft) thick, however, only the top 450 m (1500 ft) crop out within this quadrangle. The moderately thick Garley Canyon and overlying Emery Members of the Mancos Shale subdivide the formation in this quadrangle. The upper Masuk Member of the Mancos Shale is separable in outcrops south and west of the Helper Quadrangle above the intertonguing Emery Sandstone, but shale equivalent to Masuk beds is not differentiated as a separate member in the Helper Quadrangle. Shale equivalent to Masuk beds merges with the somewhat older part of the Mancos Shale east of where the Emery Sandstone pinches out in the Helper Quadrangle (fig. 3). Overlying littoral-marine sandstones of the Star Point and Blackhawk Formations also interfinger with the Mancos Shale. These coarse terrigenous tongues thin eastward and eventually grade into shale. Each successively younger sandstone tongue reaches farther eastward, which results in a stratigraphic regression of upper Mancos Shale tongues in that same direction. This makes the overall upper Mancos Shale–sandstone contact progressively younger to the east (Young 1955, p. 182). Shale tongues of the Mancos Shale have been mapped and identified with numbers 1–19 to correlate equivalent shale tongues in the Helper Quadrangle and the Standardville Quadrangle to the west (Carroll 1987).

The Mancos Shale consists of shale, silty shale, siltstone, stringers of limestone, and lenticular sandstones (Young 1955, p. 182), but calcareous, gypsiferous, bentonitic shale and silty shale predominate in the formation. Occasional unnamed sandstone lenses may be up to 1 m (3 ft) thick. They are commonly resistant and form minor cuestas. These sandstones are fine grained and weather a dark yellowish orange. Fresh samples are a light olive gray and often contain high amounts of carbonaceous material. Many small particles appear to be wood fragments. The sandstones commonly have a gradational shale-to-sand basal contact, a sharp sand-to-shale top contact, and planar lamination if bedding has not been destroyed by bioturbation.

Trace fossils comprise most organic features in the upper Mancos Shale in the Helper Quadrangle. Body fossils occur locally in siltstone and sandstone beds. Ammonoid fragments, an echinoderm (Nethercott 1986), foraminifera (Carroll 1987, Maxfield 1976), and bivalves have been collected from Mancos Shale beds within or near the Helper Quadrangle. Many of the sandstones are heavily bioturbated, and burrows up 2 cm (0.5 in) are common.

Interfingering of Mancos Shale with the Star Point and Blackhawk Formations causes a stratigraphic rise of the upper boundary of the Mancos Shale from west to east.

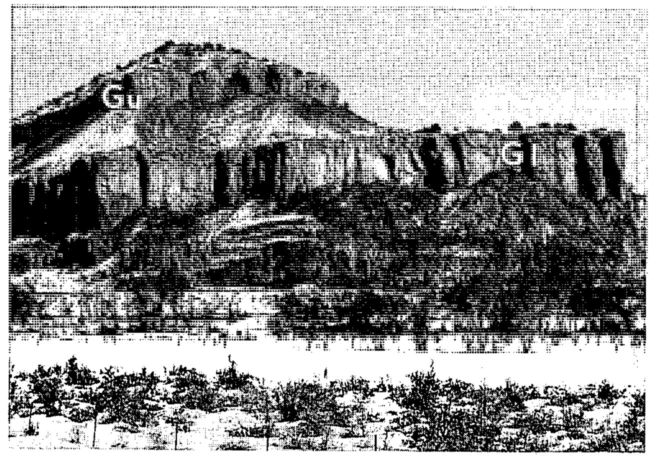


FIGURE 11.—*Cliff-forming lower (Gl) and upper (Gu) sandstones of the Garley Canyon member westward in the quadrangle (NE, NE, section 25, T. 13 S, R. 9 E). Facies I beds make up the lower part of both cliffs. Facies II beds are thin and form only a small interval at the top of each member.*

Rocks near the boundary between the Mancos Shale and Blackhawk Formation are assigned an early Campanian age in the western Book Cliffs region (Young 1966, p. 11).

Lithology and faunal evidence indicate the Mancos Shale accumulated as muds beyond the sand-mud transition line in the shallow Western Interior Seaway (Osterwald and others 1981). The shoreline configuration of the muddy Mancos Sea ran generally southwest–northeast, with a clastic supply from the nearby Sevier orogenic belt located to the northwest. Eastward regressions of the sea occurred, interrupted periodically by lesser transgressions, which resulted in eastward-thinning sandstone tongues interfingering with westward-thinning tongues of Mancos Shale. The erosional front of the Book Cliffs in the Helper Quadrangle exposes a cross section nearly perpendicular to Cretaceous shorelines and provides an excellent cross section of facies relationships created as the depositional settings changed from shallow-marine to coastal-plain environments.

Garley Canyon Sandstone Member. The Garley Canyon Sandstone Member of the Mancos Shale forms the prominent escarpment near the Carbon Country Club, along Price River, in the southwest corner of the Helper Quadrangle (fig. 11). Two cliff-forming tongues of Garley sandstone, separated by an interval of shale, extend eastward within the Mancos Shale (fig. 12), but gradually thin until they disappear under a cover of pediment gravels in the eastern part of the quadrangle. The lower sandstone tongue is 12 m (40 ft) thick in Garley Canyon, and the upper sandstone is 10 m (33 ft) thick near the country club. A shale interval of 30 m (99 ft) separates the tongues. These two tongues contain fossils that date them as Nio-

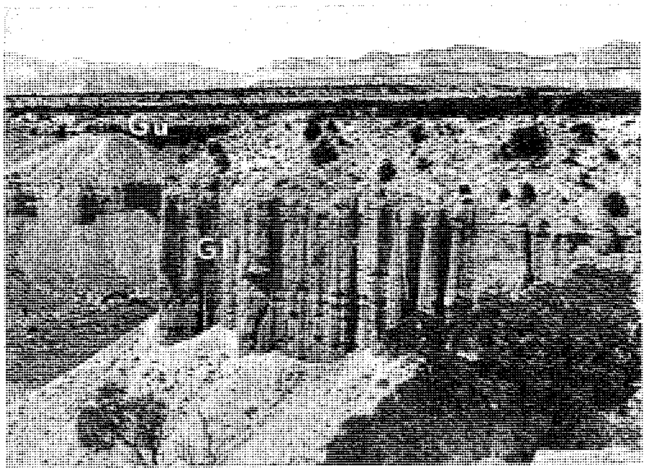


FIGURE 12.—*Eastern exposures of lower (Gl) and upper (Gu) Garley Canyon Sandstone members, NW, SW, section 34, T. 13 S, R. 10 E. Only facies I beds are present here.*

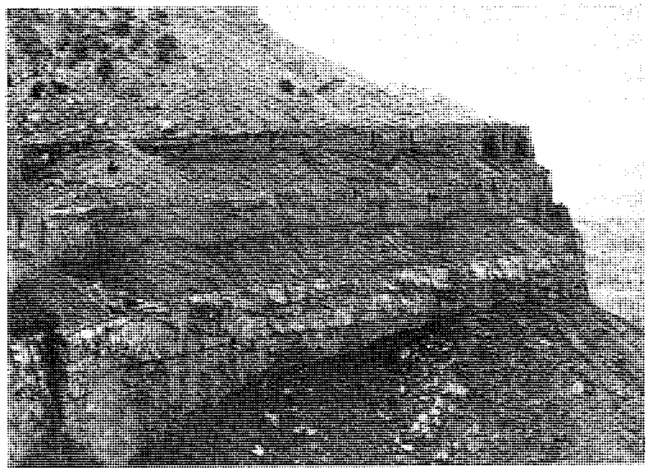


FIGURE 13.—*View southeastward of three tongues of the Emery Sandstone Member, SE, SE, section 29, T. 13 S, R. 10 E. Beds are composed of facies I and II.*

braran (Clark 1928, p. 112). Steinkerns of bivalves were found. More common, though, are trace fossils that occur throughout the bioturbated sandstones. An attempt to date the member by foraminiferal dates yielded only an Upper Cretaceous age (Carroll 1987).

Sandstone units of the Garley Canyon Member display two characteristic lithologies. Transitional units of facies I underlie both tongues and grade upward into the more massive sandstones of facies II. Facies I ranges from 3 to 9 m (10–30 ft) thick, and facies II forms an 11 m (35 ft) interval in Garley Canyon. Garley Canyon Sandstone is lenticular in regional east–west cross sections, unlike overlying sandstone tongues that thicken westward. It pinches out eastward in the Helper Quadrangle and disappears westward into Mancos Shale some distance southwest of Price.

Garley Canyon outcrops apparently bisect only the outer lobe of a delta that extended seaward from the northwest. Facies I represents pulses of sediment that prograded basinward over marine shale during storm surges or as turbidity flows. Facies II locally overlies finer sediments as shorelines approached from the west or northwest. Facies II was also deposited below normal wave base, but was reworked by storm waves, as evidenced by hummocky bedding within the unit. Sharp upper contacts of bedding planes represent successive surfaces, and each unit slopes gently seaward, where it finally grades into shale (fig. 12). The Garley Canyon Member records two periods of regression that may represent pulses of orogenic activity along the Sevier Orogenic Front, or merely a shifting focus of deltaic sedimentation.

Emery Sandstone Member. Four thin sandstone tongues, separated by intervals of marine shale, represent the Emery Sandstone Member of the Mancos Shale in the Helper Quadrangle (figs. 3 and 4). The fourth and highest tongue pinches out west of Helper, but the remaining three are recognizable eastward for several miles, until they, too, grade into Mancos Shale. The Emery Sandstone Member thickens westward and the shale intervals pinch out where the member forms a thick sandstone cliff at the west edge of the Standardville Quadrangle in Spring Canyon in section 35, T. 13 S, R. 8 E. (Carroll 1987).

The interval defined by top and bottom sandstone beds of the member is 38 m (125 ft) thick near the west edge of the quadrangle. The bottom tongue is 1.2 m (4 ft) thick, the middle is 4 m (12 ft) thick, and the top tongue is 10 m (32 ft) thick. Thickness of intervals of Mancos Shale generally increase eastward at the expense of the sandstone. Sandstone units are commonly silty and very fine grained. No body fossils were found in the member, but trace fossils are common. The sandstones commonly contain woody, carbonaceous fragments and concentrations of calcite concretions.

Sandstones within the Emery Sandstone Member are commonly thin?-bedded with southeastward dipping, planar laminations, interrupted occasionally by hummocky stratification. Individual beds, defined by silty breaks, show structure well (fig. 13). Outcrops of massive sandstone (facies II) form resistant ledges underlain by thin intervals of transitional units (facies I).

The Emery Sandstone Member represents deposition of terrigenous clastic sediments in the shallow Mancos Sea, much like the Garley Canyon Sandstone Member. The very thin transition zone marks the initial abrupt deposition of a prograding shoreline, followed by deposition of coarser sediments. Sharp upper contacts of sandstone tongues mark the disruption of sand deposition caused by transgressions of the sea. These transgressions are likely due to shifting distributaries along the coastline.

Tongues of the Emery Sandstone Member pinch out to the east, with successive, overlying tongues mappable farther eastward than the previous underlying tongue. All but the lowest sandstone tongue are thickest in the west and gradually thin eastward. The lowest tongue thickens noticeably eastwardly within the quadrangle before it too disappears into Mancos Shale in the middle of the quadrangle. Exposures of the Emery Canyon Sandstone Member probably dissect the distal portion of a delta that formed to the northwest of the quadrangle, similar to deposits related to the Garley Canyon Sandstone.

Star Point Sandstone

Star Point Sandstone consists of two eastward-projecting sandstone tongues separated by 48 m (160 ft) of Mancos Shale. The Panther Sandstone Member is the lowest sandstone tongue, and the Storrs Sandstone Member is the upper one (fig. 14). The intervening shale tongue thins westward in the Wasatch Plateau where the two members merge to form a single thick sandstone (Hansen in press). The Spring Canyon Sandstone Member of the Blackhawk Formation also joins with the massive Star Point Sandstone in the Wasatch Plateau. The Spring Canyon Tongue was originally included as part of the Star Point Formation (Spieker and Reeside 1925), but Young (1955, p. 182) reassigned it to the Blackhawk Formation.

Panther Sandstone Member. The Panther Sandstone of the Starpoint Sandstone forms an abrupt steplike cliff at the base of the Book Cliffs. It continues across the entire quadrangle, but thins from 27 m (90 ft) thick in western exposures to only 12 m (40 ft) thick in eastern ones.

Several different facies occur in the Panther Member, but the most distinctive outcrops are those in the type area in Panther Canyon, a tributary to Price Canyon

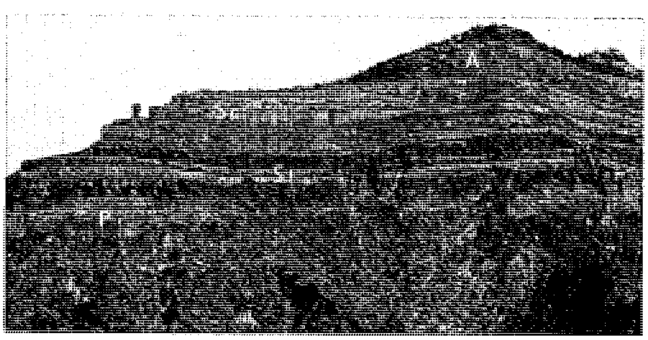


FIGURE 14.—*The Book Cliffs north of Helper. Talus covers the slopes of Mancos Shale. Outcropping members are the Panther (P), Storrs (St), Spring Canyon (Sc), and Aberdeen (A) Sandstones.*

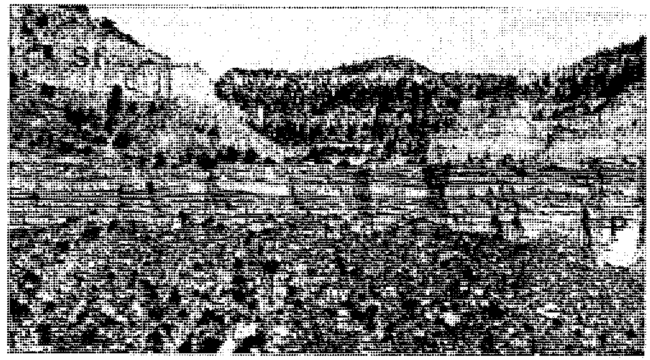


FIGURE 15.—*Panther Sandstone Member at the type section in Price Canyon (NE, SW, section 12, T. 13 S, R. 9 E). Note dipping beds of facies III underlain by facies I beds. Two tongues of the Storrs Sandstone Member overlie the Panther Sandstone Member.*

between Helper and the old townsite of Castle Gate (fig. 15). This outcrop is largely facies III. Medium-grained sandstone sets, separated by shaly siltstone intervals, make up these large-scale, southwest-dipping cross-beds. Each individual tabular sandstone of this facies may be traced down the dip of the set until it grades with underlying, horizontal siltstones of facies I and II. Howard (1966a, 1972) studied the Panther Sandstone in detail and found this facies present in the area of Price Canyon. From sole markings in facies III, he determined that paleocurrents were to the southwest and parallel to the dip of the large-scale cross-beds.

Sandstone of facies III are laterally replaced by facies II eastward. Facies II is cut westward and replaced by a massive channel-fill sandstone 5 km (3 mi) west of the Helper Quadrangle (Carroll 1987). This channelled facies is highly cross-bedded, coarse-grained sandstone. The sandstone appears massive from a distance, but is cross-laminated throughout and composed of numerous channel-fill sandstones. The lowermost beds of the Panther Member there are composed of facies I, like in outcrops to the east. Facies I actually makes up the bulk of the member in most outcrops east of Price Canyon.

Howard (1972) concluded that the Panther Sandstone originated as part of a delta, and the dipping tabular sandstones represented delta-front beds and the channel sandstone facies represented fluvial channel deposits. He also interpreted facies I as prodelta beds and facies II as delta-front transition beds.

During the Cretaceous, paleoshorelines trended approximately NE–SW across central Utah. Clastic sediments eroded from contemporaneous orogenic features were spread by numerous small streams and accumulated in deltas along a wave-domimated coastline (Ryer and McPhillips 1983, p. 268). The steep regional slope and abundant sediment supply created a regressive shoreline,

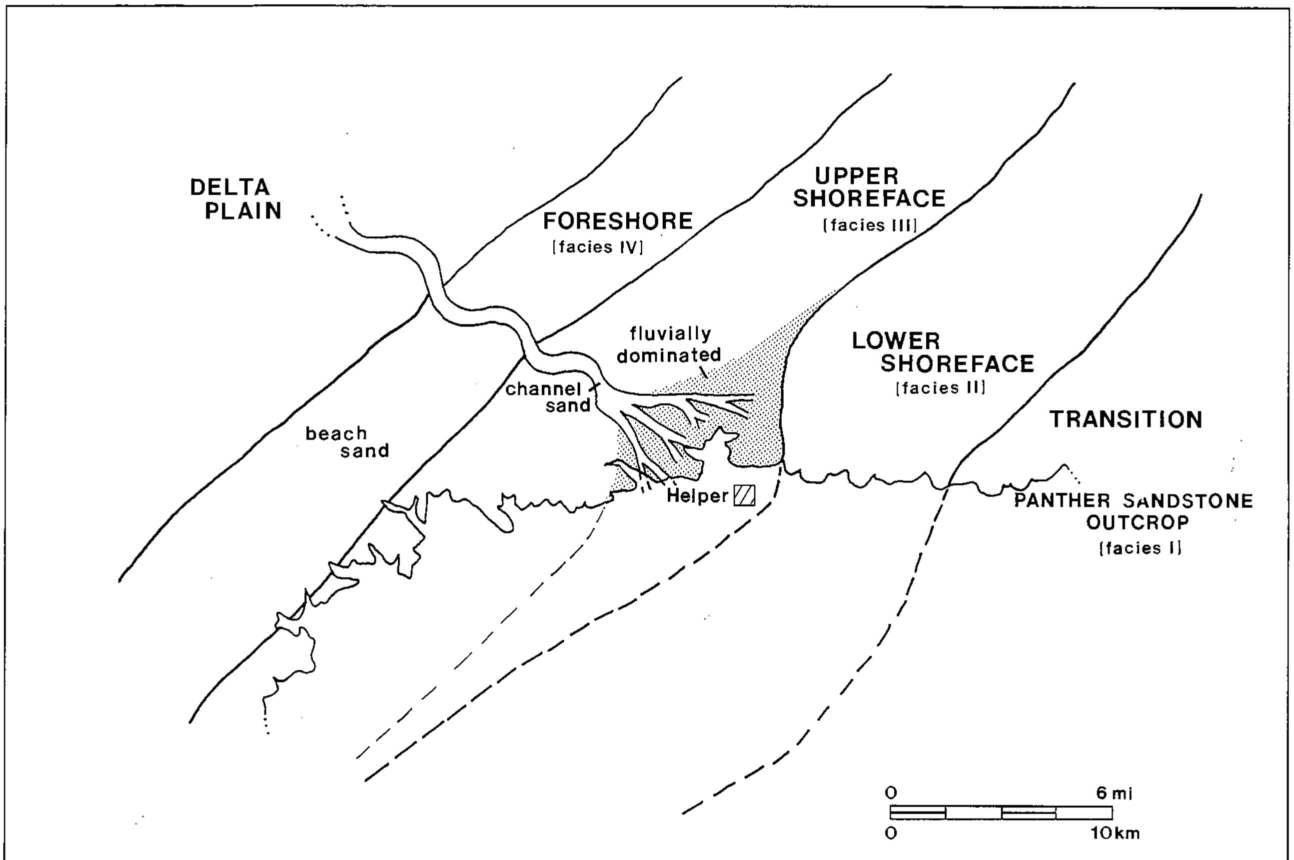


FIGURE 16.—*Depositional model of the Panther Sandstone Member from distribution of sandstone facies (Howard 1972). Facies map shows approximate location of the maximum seaward extent of the Panther delta in the Helper Quadrangle.*

like that discussed by Heward (1981). Rivers deposited terrigenous debris that was reworked to form arcuate, wave-dominated deltas (fig. 16). Tabular sandstone of facies III of the Panther Tongue represents the dipping distributary beds of the delta front (fig. 15). The channel sandstone facies exposed in Spring Canyon (section 16, T. 13 S, R. 9 E) represent distributary mouth-bar deposits. Shaly siltstones interbedded with sandstone lack the sorting common in facies III of other littoral sandstones in the quadrangle. This only moderate sorting occurs because the outcrop was near the focus of rapid sedimentation. Fluvial processes dominated near the river mouth, but longshore currents reworked the sediments laterally. Well-sorted sandstones were then deposited away from the river mouth, and are found in Panther Member exposures to the west and south along the east front of the Wasatch Plateau (Hansen in press, Howard 1966a, 1966b).

Lateral replacement of channelled sandstones or facies III by facies I and II indicate deposition away from the delta and river mouth, and water of increasing depth. Facies II reflects sandy sedimentation of the delta front, which was below tidal range, but within reach of storm surges, as suggested by development of hummocky beds. Facies I was deposited below wave base from suspension, near the basinward limit of sand deposition. Storms and floods also incorporated woody debris from streams or along the coastline. The rhythmic nature of the facies records the effects storms or floods had on deltaic sedimentation.

Storrs Sandstone Member. The Storrs Sandstone Member of the Star Point Sandstone crops out between the Panther Sandstone and the overlying Blackhawk Formation along the Book Cliffs (figs. 14 and 15). It is composed of two sandstone tongues that appear as vague, low ledges throughout most of the outcrop belt. The lower tongue is 8 m (25 ft) thick, and the upper tongue is about 3 m (11 ft) thick near the west edge of the quadrangle, where a 12 m (39 ft) tongue of Mancos Shale separates the sandstones. The lower sandstone thickens westward and merges with the Spring Canyon Member of the Blackhawk Formation near Storrs, in the Standardville Quadrangle (Carroll 1987). It thins and almost disappears near the eastern edge of the quadrangle. The upper tongue is lenticular and rapidly thins both to the east and west from its 3 m (11 ft) thick exposure in Price Canyon.

The lower sandstone tongue is composed of rocks of facies I and II. Facies II beds are thin and present only in western outcrops. Beds of facies II do not extend eastward from outcrops directly north of Helper, although facies II beds do. Rocks of facies I form the base of the lower Storrs tongue throughout the Helper Quadrangle and characterize the entire upper tongue.

Eastern limits of the Storrs tongues represent the basinward margin of sandstone deposition. Facies I and II indicate transitional and prodelta regimes similar to those of the Panther Sandstone Member.

Blackhawk Formation

Massive sandstone cliffs separated by slopes of siltstone and shale make up exposures of the coal-bearing Blackhawk Formation. Four sandstone members and four interbedded coal-bearing mudstone members have been separately mapped in the Helper Quadrangle (fig. 17).

The Spring Canyon Sandstone Member lies at the base of the formation and is directly overlain by a section of coal, siltstone, and shale, here termed mudstone member 1. The Aberdeen, Kenilworth, and Sunnyside Members are successively younger sandstone members and are overlain by mudstone members 2, 3, and 4, respectively. Young (1955) previously subdivided the Blackhawk Formation into only four members in the Helper Quadrangle and grouped a sandstone with its overlying mudstone interval as one member. Maberry (1971) found it helpful to separate coal-bearing mudstone sections from sandstone units. This report combines elements of both nomenclatures. Sandstone units are named following Young's usage, but mudstone units are separated and numbered. The Blackhawk Formation reaches a maximum thickness of 375 m (1250 ft) near Castle Gate and gradually thins eastward. It is 327 m (1090 ft) thick at the east boundary of the Helper Quadrangle and continues to thin eastward (Anderson 1978, Nethercott 1986, Willis 1986).

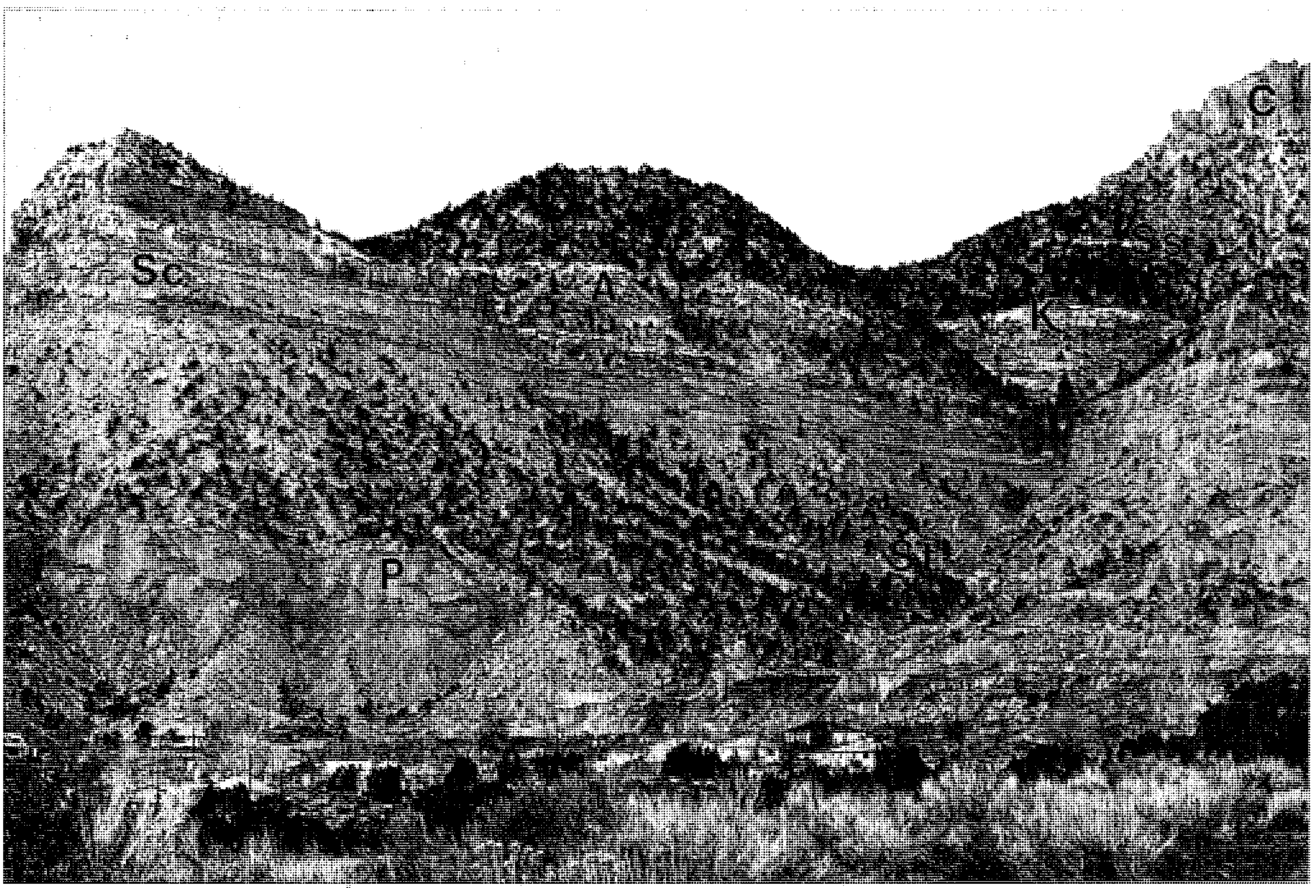


FIGURE 17.—*Blackhawk Formation north of Kenilworth (section 16, T. 13 S, R. 10 E). Talus covers Mancos Shale slopes. Outcropping members are the Panther (P), Storrs (St), Spring Canyon (Sc), Aberdeen (A), Kenilworth (K), and Sunnyside (Ss) Sandstones. The Castlegate Sandstone (C) appears in the upper right corner.*

All sandstone members, except the Kenilworth Member, are made up of two or more individual sandstone tongues (fig. 18). These stacked tongues commonly form a single sandstone cliff in western exposures, but separate and pinch out to the east. They are divided by tongues of Mancos Shale that thicken gradually eastward at the expense of the sandstone member. Each successively younger tongue develops farther eastward in shinglelike fashion in the regressive sequence, so facies generally rise stratigraphically to the east. All Blackhawk Sandstone members thin and eventually disappear into mudstone members west of the quadrangle.

Individual sandstone tongues within the Blackhawk Formation are composed of rocks of facies I thru IV (figs. 5 and 6), which rest gradationally on beds of the Mancos Shale. Thickness and lateral extent of individual facies vary greatly, but as a general rule, lithology I beds develop at the base, successively overlain by beds of facies II, III, and IV. A complete sequence of facies I through IV beds need not occur as facies I often makes up an entire sandstone tongue in eastern sections. Repetition of sandstones of facies I and II then overlain by facies III and IV beds are commonly found throughout the Blackhawk Formation.

Exceptions to this pattern occur, however, as westernmost exposures of a sandstone tongue may contain only facies III and IV, which are channelled into rocks of the mudstone members. Rocks of facies IV, often white-capped units, form broad platforms on which thick coals developed.

Spring Canyon Sandstone Member. The Spring Canyon Member contains five sandstone tongues that occur on top of each other in shinglelike fashion (fig. 18). Each superjacent tongue carries farther east than the one it overlies. Four of the tongues occur in Price Canyon. An additional, overlying tongue begins east of the canyon and thickens eastward. The stacked tongues give the appearance in some locations of a single unit (fig. 19). The lower two members pinch out before reaching the west quadrangle boundary, and the middle and upper two continue eastward across the quadrangle into the Deadman Canyon Quadrangle (Nethercott 1986).

The Spring Canyon Member is thickest, nearly 87 m (260 ft) thick, near Helper Canyon. The interval between upper and lower tongues actually increases eastward. This is due, however, to thickening intervals of Mancos Shale between the bottom or first and second tongues.

The lowest tongue consists of facies I, II, and III beds, 5 (15 ft), 3.5 m (10 ft), and 3 m (9 ft) thick, respectively, in Price Canyon (fig. 18). The tongue thins eastward and loses facies II and III near Helper Canyon. A tongue of marine shale about 1.5 m (5 ft) thick in Price Canyon thickens to more than 10 m (30 ft) thick at Cordingly Canyon, where the shale tongue pinches out to the west.

The second tongue also consists of facies I, II, and III beds. The tongue is about 17 m (50 ft) thick in Price Canyon. It loses facies III near Helper Canyon, but maintains facies I and II eastward across the quadrangle. Beds of both facies thin to form a 1.5 m (5 ft) thick tongue in Alrad Canyon. A shale tongue overlies this sandstone tongue near Helper Canyon and rapidly thickens eastward to 17 m (50 ft) thick in Alrad Canyon.

The third tongue has beds of facies I, II, III, and IV. It is about 24 m (70 ft) thick in Price Canyon. The basal tongue contains alternating beds of facies II and III. A 7 m (20 ft) interval of facies III beds overlies the alternating series and is overlain by an 2.5 m (8 ft) thick bed of white-capped facies IV that caps the unit. The white-capped facies disappears near Helper Canyon, and the tongue develops basal facies I, which thickens eastward. Beds of facies II thin eastward and disappear near Kenilworth, but a measurable thickening in facies III, which rests directly on facies I east of Kenilworth, and facies I of the tongue, maintains a thickness of about 17 m (50 ft) across the quadrangle. Beds of facies III within this tongue differ slightly from underlying facies III beds. Abundant silty beds and gently inclined, south- to southwestward dipping, tabular sets replace the usually massive appearance of the facies. These irregularly bedded, cross-stratified beds are 10–14 m (30–40 ft) thick in Cordingly and Alrad Canyons.

The fourth tongue also contains beds of facies I–IV in Price River Canyon. The 14 m (40 ft) thick sandstone has a 1.5 m (5 ft) thick base of facies I, a 7.5 m (23 ft) thick section of alternating beds of facies II and II, and a 4 m (12 ft) thick white-capped section of facies IV. A 1.5 m (2) thick coal overlies the sandstone in the canyon. The coal thickens west of Price Canyon, where it becomes a minable seam (sub 2 seam), but thins eastward. It pinches out under the wedge of a fifth sandstone tongue that first appears east of Helper Canyon (fig. 19). Facies IV beds disappear east of Helper Canyon, and facies III beds thin out near Kenilworth. Thickening in both facies II and III maintains the tongue's thickness eastward from Kenilworth to Alrad Canyon, where facies I is 14 m (40 ft) thick and facies II is 7.5 m (23 ft) thick.

The fifth tongue is developed between Panther and Helper Canyon. It is the youngest and thickest sandstone tongue that occurs in the Spring Canyon Member (fig. 19). It includes basal beds of facies IV that rest directly on a thin coal (sub 2 seam). The tongue rapidly thickens eastward because of the progressive development of underlying facies III, II, and I. All four facies are present at Kenilworth. Facies IV disappears immediately east of Kenilworth. A 5 m (15 ft) thick section of facies III beds, a

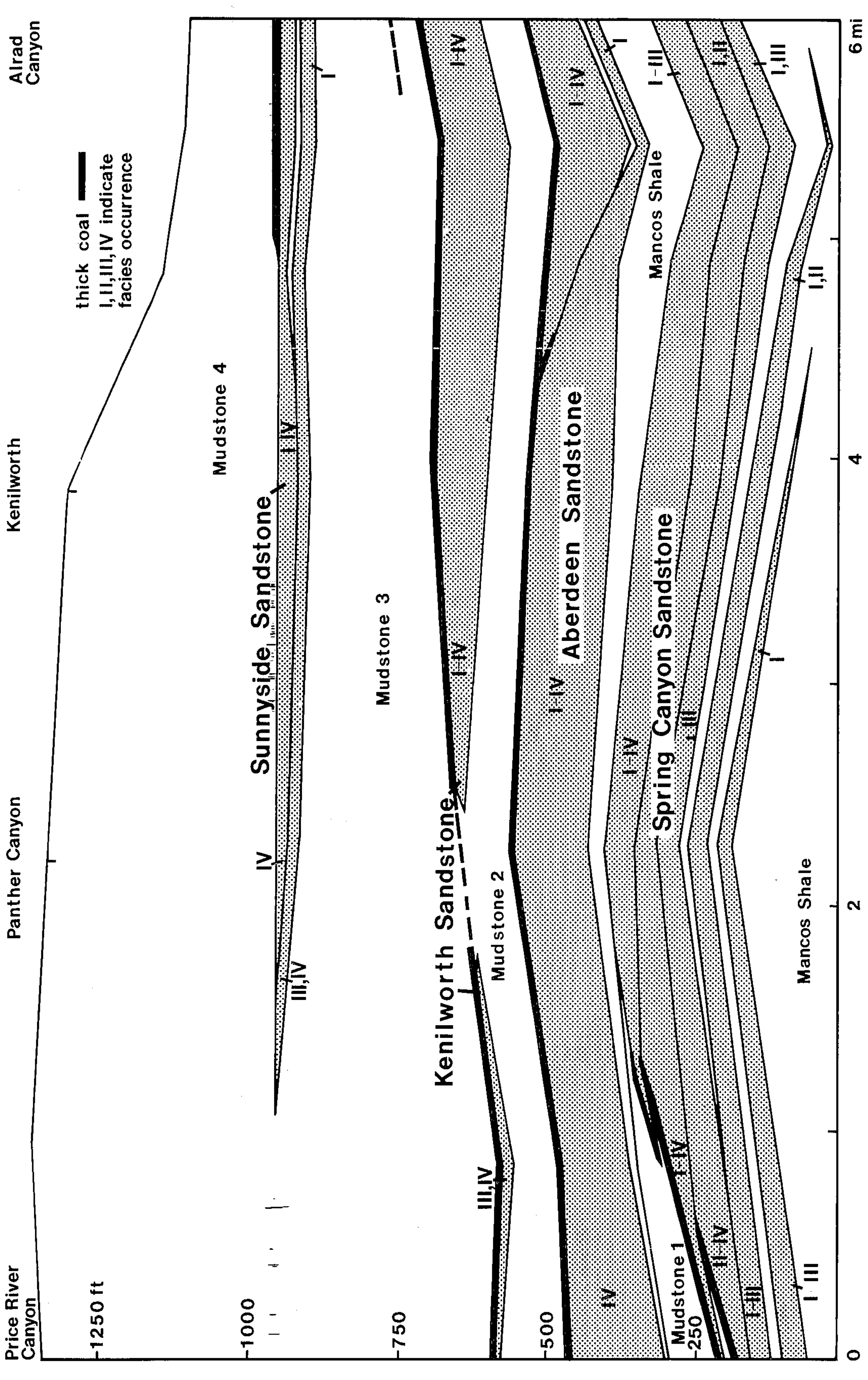


FIGURE 18.—*Cross section of the Blackhawk Formation that shows development of multiple tongues within individual sandstone members, and facies distribution within each tongue. Also shows intertonguing relationships with marine shale and terrestrial mudstones and coal.*

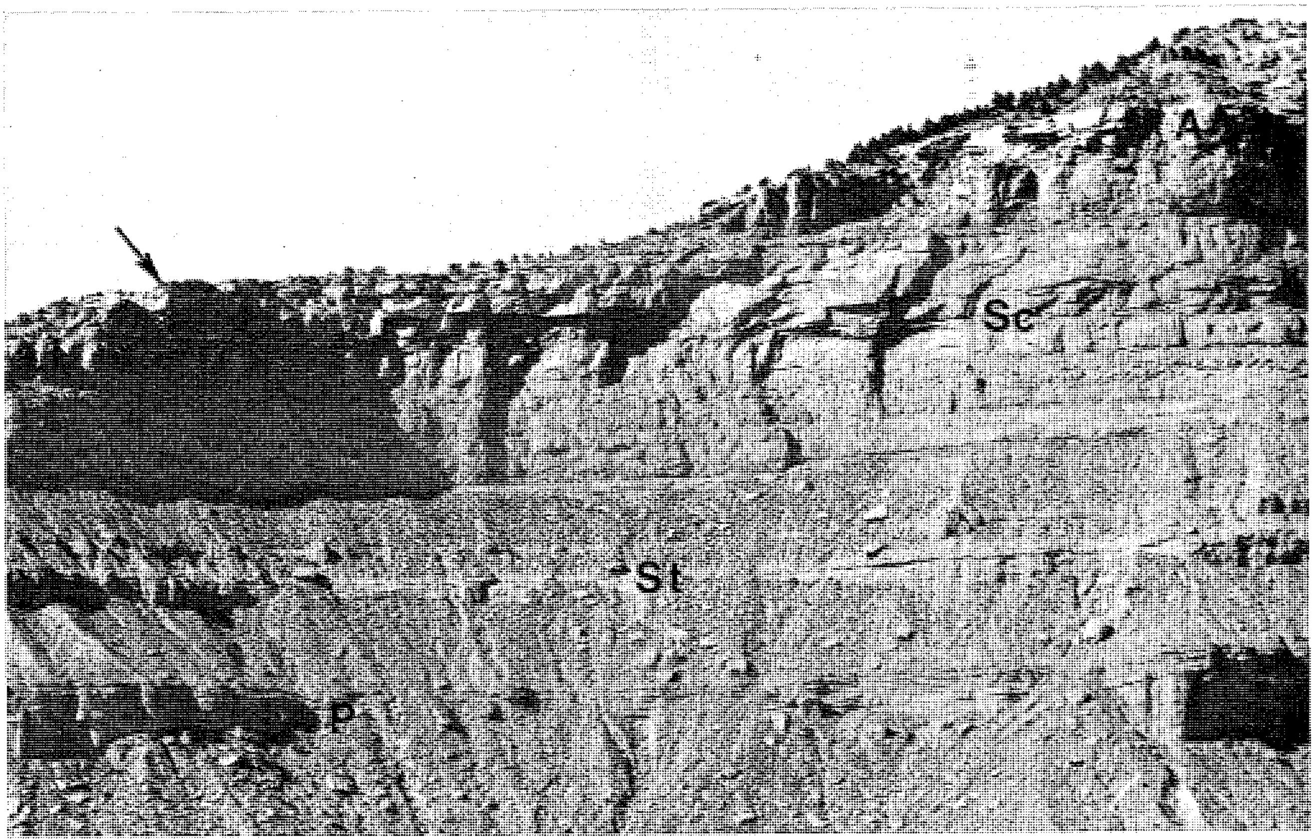


FIGURE 19.—*Spring Canyon Sandstone Member (Sc) north of Helper (section 13, T. 13 S, R. 9 E). Five tongues of the member give the appearance of a single unit. Arrow points to the fifth tongue, which caused underlying coal to pinch out. Other members exposed are the Panther (P), Storrs (St), and Aberdeen (A) Sandstones. Mancos Shale separates each sandstone tongue.*

3 m (10 ft) thick section of facies II beds, and a basal 15 m (45 ft) thick section of facies I beds are fairly constant from Kenilworth eastward into Alrad Canyon.

The Spring Canyon Sandstone was deposited along a sandy, wave-dominated shoreline. Beds of facies I and II developed along the transition and lower shoreface of the delta. Facies III show the effects of deposition in the high-energy regime of longshore currents along the upper shoreface. Cross-stratification indicates a general southwest direction of transportation. This fits in well with a regional northeast–southwest paleoshoreline direction determined by 4500 cross-bed measurements made by Balsley (1982) in different locations of the Blackhawk Formation. Facies IV was deposited along the sloping sandy foreshore or beach. Tabular and gently inclined beds of facies III east of Kenilworth indicate the proximity of a distributary mouth, much as do those of the previously discussed Panther Sandstone. Channel-fill sandstone and dissected delta-front sandstones represent distributaries that flowed across the delta plain and incised previous deposits (fig. 20).

Numerous stacked sandstone tongues in Price Canyon indicate rapid subsidence, especially in comparison to westward extensions of the member. The member consists of only two tongues throughout most of the Standardville Quadrangle (Carroll 1987) and has well-developed coal on and above them. The coal thins and disappears completely where underlying sandstone tongues stack up in Price Canyon. Thin Mancos Shale tongues that separate lower sandstone tongues represent periods of marine transgressions. Frequent marine transgressions over the rapidly subsiding sandstone drowned the delta platform before upper delta facies and coal swamps could develop.

Mudstone member 1. Mudstone member 1 occurs on top of the Spring Canyon and contains the feather edges of coals that are thicker to the west. It is 19 m (56 ft) thick in Price River Canyon and thins out completely 2 mi east of the canyon (figs. 14 and 18).

The mudstone unit contains interbedded lenticular channel-fill sandstones and interchannel, carbonaceous siltstones and coals. Thicker coals developed at the mudstone base, and highly lenticular, thinner coals occur in upper sections. Black, organic shale is interbedded within or around coal. The sandstone and siltstone contain abundant carbonized plant debris. Whole plant fossils of

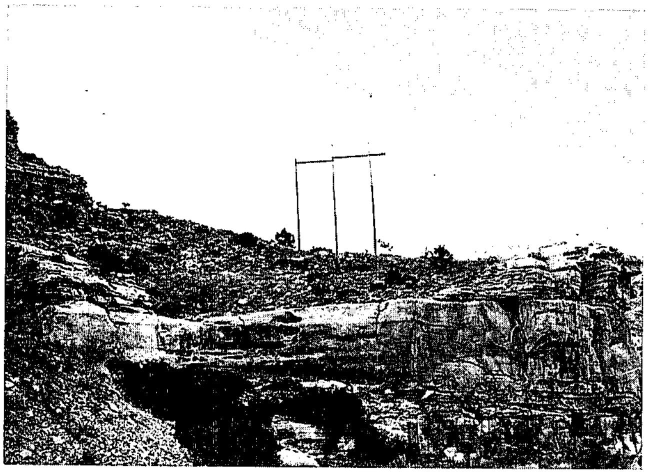


FIGURE 20.—*Paleofluvial channel incised into the top beach sandstone of the Spring Canyon Member in Price Canyon (NW, NW, section 1, T. 13 S, R. 9 E).*

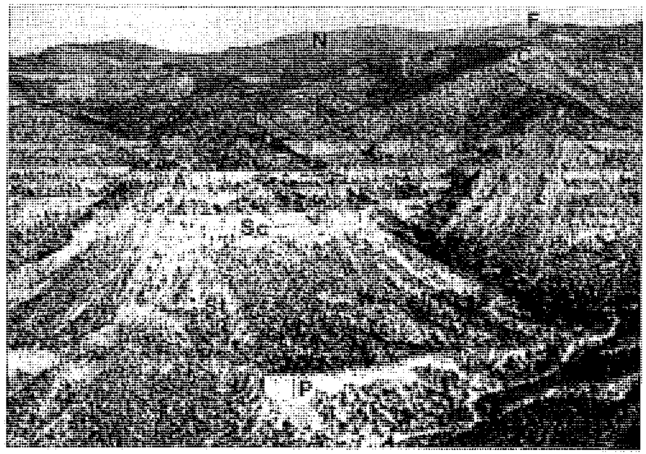


FIGURE 21.—*Aerial view of the west wall of Alrad Canyon looking north (section 13, T. 13 S, R. 10 E). The (A) member here has two tongues. Other outcropping members are the Panther (P), Storrs (St), Spring Canyon (Sc), Kenilworth (K), and Sunnyside (Ss) Sandstones. Above are the Castlegate (Cg), Price River (P), North Horn (N), and Flagstaff (F) Formations.*

Araucaria, Fiscus, Salix, Sequoia, Metasequoia, and *Protophyllocladus* occur throughout the mudstone (Carroll 1987). Sandstones have grayish tones and are heavily cross-bedded, especially near their base. Laminations become horizontal upward in the sandstone. Differential compaction of coals, shales, and sandstones has distorted bedding. Sandstones and siltstones have undergone extensive bioturbation, and *Pelecypodichus*, a freshwater fossil, occurs commonly in the member (Balsley 1982).

Major coal seams of the member include the sub 1, 2, and 3 seams of the Spring Canyon Coal Group. All are too thin to mine east of Price Canyon, but all three seams are economical to mine west of the canyon. The coal seams pinch out underneath the western edge of stacked sandstone tongues of the Spring Canyon Member (fig. 18).

Rocks of the mudstone member originated in the broad fluvial plain that prograded eastward across underlying delta-front sandstones. Numerous, low-sinuosity streams flowed eastward across the delta plain and deposited thin channel sandstones and floodplain sediments. Thicker coals developed directly on the broad delta plain, and minor coals developed in interchannel areas of the coastal plain. Occasional floods topped the banks and spread sand into lower areas.

A westward-thinning tongue of Mancos Shale rests conformably on top of the mudstone; this shale tongue represents a marine transgression during which the shoreline was located several miles west of Price Canyon. This transgression likely followed delta subsidence after distributary abandonment.

Aberdeen Sandstone Member. The Aberdeen Sandstone in the Helper Quadrangle consists of one sandstone tongue throughout most of the quadrangle (figs. 17 and 18). A second overlying tongue develops near Cordingly Canyon. The member pinches out into mudstone members in the Wastach Plateau, but is mappable for 20 mi to the east. The Aberdeen Member forms an important horizon, as all economic coals of the quadrangle lie above it. A distinctive white unit caps the Aberdeen Member throughout most of its exposure.

The Aberdeen Member is 36 m (109 ft) thick in Price Canyon, and all four sandstone facies are present. Facies I beds—23 m (68 ft) thick—underlie a 7 m (20 ft) interval of facies II, a 4 m (13 ft) interval of facies III beds, and a 2.5 m (8 ft) interval of facies IV beds, which have a distinct white cap. All but facies I thicken toward Kenilworth, where beds of facies I, II, III, and IV are 10, 23, 10, and 3 m (30, 70, 30, and 9 ft) thick, respectively. Facies II–IV beds thin rapidly eastward and pinch out before reaching Alrad Canyon.

A second overlying tongue is differentiated in Cordingly Canyon where it begins as a thin tongue of facies IV beds (fig. 21). The tongue gradually gains facies III, II, and I eastward. All four facies are present in the tongues in Alrad Canyon. They overlie a 3 m (10 ft) interval of Mancos Shale, which separates them from facies I beds of the first Aberdeen tongue. Beds of facies I–IV are 10, 17, 7, and 5 m (30, 50, 20, and 15 ft) thick in Alrad Canyon, where the lower Aberdeen tongue is about 8 m (25 ft) thick.

Well-developed delta-front sequences suggest that the Aberdeen delta prograded consistently over prodelta and basinal marine shales for many miles before the delta-producing stream was diverted or increased subsidence drowned its advance. The Aberdeen sandstone tongues stacked up in the Cordingly Canyon area with the appear-

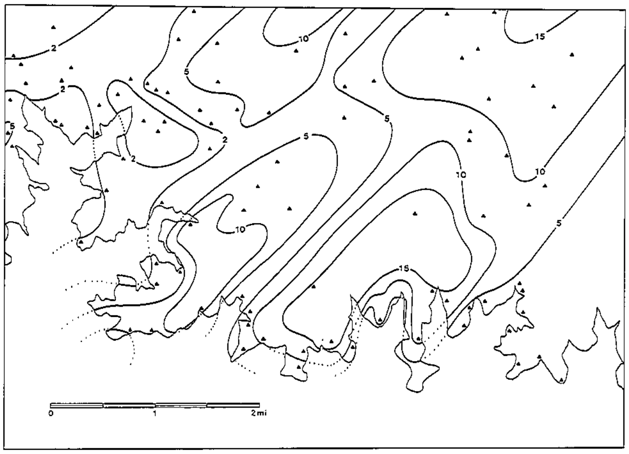


FIGURE 22.—*Isopach of the Aberdeen coal seam in the upper half of the Helper Quadrangle. Thinned coal in an east–west line through the upper part of the map probably indicates fluvial channeling of the coal. Coal trends suggest that paleoshorelines ran approximately northeast–southwest. Thickness is in feet, triangles indicate data points, and the fine line indicates the coal outcrop.*

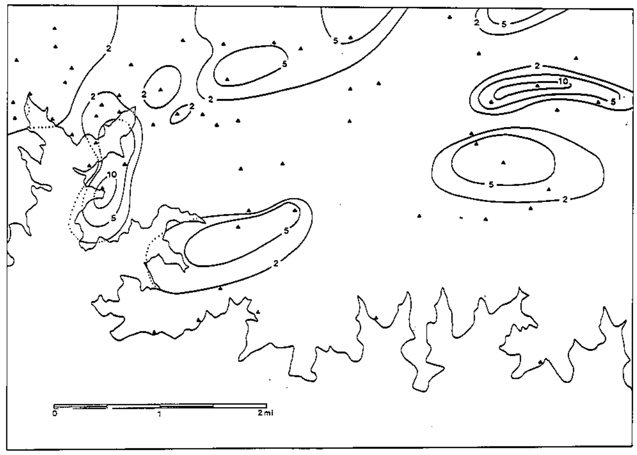


FIGURE 23.—*Isopach of the Castlegate B coal seam in upper half of quadrangle. Lineation and elliptical nature of the coal thickness suggests swamps were controlled by streams that flowed southeastward. Thickness is in feet, triangles indicate data points, and the fine line indicates the coal outcrop.*

ance of its second tongue. The member rapidly gains several more tongues immediately east of the Helper Quadrangle (Nethercott 1986). Stacking and thickening of Aberdeen Sandstone tongues resemble the pattern observed in the Spring Canyon Member in Price Canyon.

Mudstone member 2. The mudstone member 2 forms a consistent interval of interbedded lenticular channel sandstone, interchannel carbonaceous siltstones, and coals directly above the Aberdeen Sandstone (fig. 18). The member is about 33 m (100 ft) thick in Price Canyon and thins to 27 m (80 ft) thick in Alrad Canyon. Mudstone member 2 resembles mudstone member 1, except the coal and sandstone channels are thicker. Freshwater fossils, channel-fill sandstone, limestone lenses, and overbank deposits suggest deposition in a fluvial coastal plain. Sediments of these environments prograded seaward across the broad platform built of delta-front sandstones. High water tables allowed the development of lakes and interchannel swamps in lower reaches of the coastal plain. Coastal plain environments graded into vast delta plain swamps that developed directly upon beach ridge sandstones.

Coals of this mudstone member include the Castlegate A, or Aberdeen seam, the Castlegate B and Castlegate C east (includes the laterally equivalent Royal Blue seam), and numerous thin discontinous seams.

The Castlegate A seam developed directly on sands of the Aberdeen delta plain; this indicates that vegetation extended down to the active shoreline. High water tables developed behind the shoreline as sediments compacted and large swamps developed directly on the beach sand. These large swamps produced a coal seam that begins west of Price Canyon and extends throughout the Helper Quadrangle into the Deadman Canyon Quadrangle. Coal seams up to 7 m thick occur in the Helper Quadrangle (fig. 22). Coal is quite thin in an east–west-trending swath in the northern part of the quadrangle. This shows the effects that fluvial channels had on deposition, either inhibiting or channeling coal deposition. This channelled area continues westward throughout the Standardville Quadrangle (Carroll 1987).

Castlegate A coal is thickest where it overlies only one well-developed delta-front sandstone tongue (fig. 18). The thickest part of the seam trends NE–SW, which is parallel to paleoshorelines. The coal thins rapidly where a second sandstone tongue developed in the Cordingly Canyon area. Several more tongues stack up just east of the quadrangle. These stacked tongues provided a barrier behind which thick peat accumulated on the broad delta plain. Coastal or upper delta plains deposits prograded over the peat and deposited the mudstone members that contain the thinner coals of the Castlegate B and C seams. These coals are thickest parallel to east–west streams that flowed through the swamps (fig. 23). Minor coals accumulated in backswamp regions farther up the coastal plain. Minor marine invasions are recorded by thin layers of mudstone that contain brackish water faunas. These fossils include *Corbula, Ursirvus, Anomia,* and *Brachiodontes* (Nethercott 1986). These layers lie directly on the Aberdeen seam in places, and elsewhere occur in stratigraphically higher coastal plain sediments.

Kenilworth Sandstone Member. The Kenilworth Sandstone Member is 7 m (20 ft) thick in Price Canyon and thickens rapidly east of Kenilworth (fig. 17). This member shows facies relationships not seen in underlying Blackhawk sandstones in this quadrangle, for facies III and IV beds of the tongue lie directly on beds of mudstone member 2 in Price River and Willow Creek Canyons (fig. 18). The base of the sandstone contains abundant rip-up clasts derived from the eroded surface of mudstone member 2. The member includes a 2 m (6 ft) thick basal section of facies I and a 13 m (38 ft) thick section of facies II beds north of the town of Kenilworth. Overlying facies III beds thicken to 8 m (24 ft) and facies IV beds thicken to 6 m (18 ft). Eastward, beds of facies I, II, III, and IV become 10, 15, 3, and 5 m (30, 45, 10, and 16 ft) thick, respectively, in Alrad Canyon (fig. 21). The Kenilworth pinches out into mudstones 1.5 km west of the quadrangle boundary in the Standardville Quadrangle. Earthy red and orange colors characterize outcrops of this sandstone that are stained by overlying rocks and clinkered by extensive burning of overlying coals. Intense heat has destroyed primary features of the outcrop and often disguises its appearance.

The Kenilworth Sandstone represents renewed delta plain sedimentation over transgressed coastal plain deposits. A new, sandy shoreline established itself just west of Price Canyon as an influx of sediments fanned out into the shallow water. Waves churned submerged coastal plain sediments before depositing a thin blanket of upper shoreface and foreshore sandstones. Water was not deep enough (below wave base) to initiate deposition of lower shoreface and transitional units until the delta prograded several miles seaward. Swamps grew on its surface and accumulated vast amounts of peat as the delta prograded.

The Kenilworth Sandstone abruptly thins and disappears 1.5 km northwest of Kenilworth (figs. 18 and 24). A zone of highly clinkered coastal plain rocks replaces it. It reappears 3 km east of this point. The missing Kenilworth may have resulted from erosion by streams soon after deposition, or it may represent a topographically high section that received no deltaic sedimention. Numerous small channel deposits at the Kenilworth horizon suggest that east–west flowing streams eroded the delta-front sands. Also, a steep ramp created by the eastward reappearance of the sandstone forced miners to veer downdip in order to maintain grade while mining coal directly above the sandstone (Laine Adair personal communication 1983). This suggests that a fluvial channel system entrenched the wide swath in the beach-front sands.

Mudstone member 3. A thick section of coastal plain muddy deposits developed on top of the Kenilworth sand (fig. 21). This member merges with mudstone member 4 in Price Canyon because the Sunnyside Sandstone that divides the two does not reach this far west (fig. 18). The member is 72 m (215 ft) thick in Alrad Canyon. The rocks of this member are similar to those of mudstones 1 and 2, and collected in much the same way. Extreme clinkering has destroyed many primary features and imparted bright red and orange colors to the member. Important coals of the member include the Kenilworth, Castlegate C west, Castlegate D, E, F, and Gilson seams.

The Kenilworth coal seam rests directly on top of the Kenilworth Sandstone Member and is the most important seam of the quadrangle. Vast swamps accumulated thick peat directly behind sandy beaches at the shoreline. Coals that resulted measure up to 9 m (27 ft) thick in places (fig. 25). A swath of thinned Kenilworth coal runs east–west across the quadrangle and represents an area channelled by streams that flowed across the delta plain. Coal of the Kenilworth seam is thickest when underlain by a single, well-developed sandstone tongue (fig. 18).

Stacking of underlying Aberdeen sandstone tongues to the east in Deadman Canyon formed a sandy barrier behind which highly compactable mud and peat of mudstone member 3 accumulated. Little compaction occurred in the underlying sandstone column, and swamp accumulations thickened appreciable on the delta plain west of the sandy column. These swamps expanded westward several times into the upper delta plain and were subsequently buried by prograding upper delta plain sediments. This explains the origin of three westward splits of the Kenilworth seam that separate west of Kenilworth. The lower seam is still the Kenilworth seam, the middle is the Castlegate C west, and the top split is the D seam. A seam eastward in Cordingly Canyon overlying Kenilworth coal is also called the D seam, but is likely a separate seam. This eastward D seam and overlying, local E and F seams are likely of upper delta plain origin. The Gilson, which is economically important in the Deadman Canyon Quadrangle, extends slightly into the Helper Quadrangle. Development of thicker coals to the east, such as the Gilson bed, indicates that prograding coastal plain sediments finally overwhelmed the noncompacting Aberdeen sandstone column and deltaic sediments prograded farther eastward into the basin. Numerous minor coals continued to develop in interchannel lowlands and oxbow lakes of the coastal plain that also prograded eastward.

Fossil evidence indicates that conifers such as *Sequoia* and *Araucaria* dominated the swamp environment (Parker 1976). Parker suggested that coniferous fossils were better preserved because of their woody nature, and stated that angiosperms, such as *Rhamnites*, could have also flourished as well. Numerous palm leaves and ferns are also abundant. Dinosaur tracks, which are commonly found in the roof rock of mines, indicate that three-toed

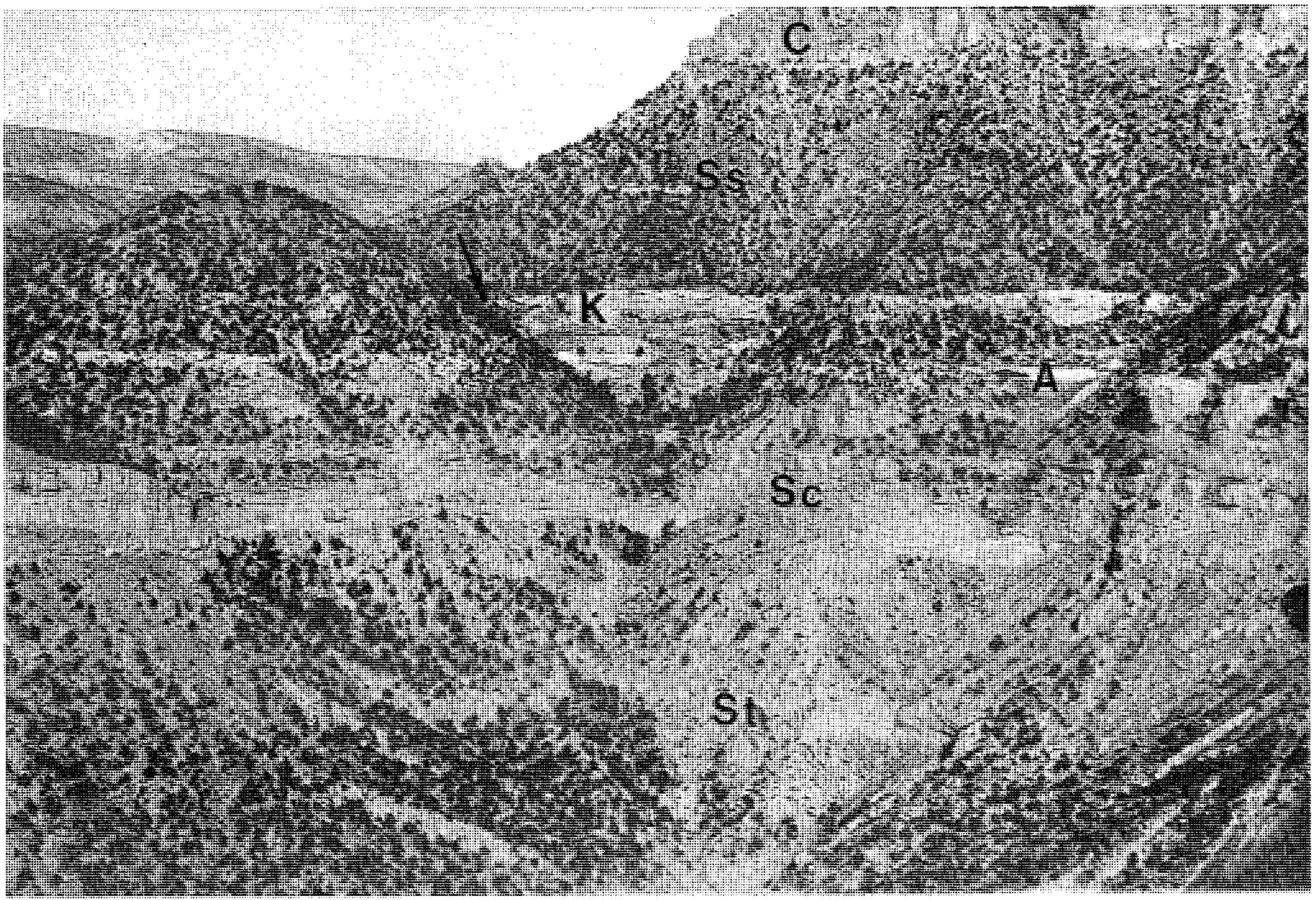


FIGURE 24.—*Aerial view northward, west of Helper. Arrow indicates where the Kenilworth Sandstone Member (K) rapidly pinches out westward (SE, NE, section 17, T. 13 S, R. 10 E). Other outcropping members are the Storrs (St), Spring Canyon (Sc), Aberdeen (A), and Sunnyside (Ss) Sandstones. Mancos Shale separates members below the Aberdeen Member, and mudstone members overlie the other sandstones. The Castlegate Sandstone (C) overlies mudstone member 4.*

dinosaurs occupied the swamp habitat. Lee Parker (personal communication 1984) reported that most tracks are of hadrosaurs, duck-billed dinosaurs.

Sunnyside Sandstone Member. Two thin sandstones of the Sunnyside Member are traceable from Willow Creek Canyon into the eastern part of the quadrangle (figs. 18 and 21). The lower tongue almost reaches Price Canyon, where it becomes unmappable. Poorly developed units of facies III and IV make up the member in western exposures and rest on an eroded base of mudstone member 3. Only the lower tongue is present near Kenilworth, where beds of facies I are 15 thick, facies II is 2.5 m (8 ft) thick, facies III is 3 m (10 ft) thick, and facies IV is 6 m (19 ft) thick. Beds of facies I make up the lower tongue in Alrad Canyon where it is 3.5 m (11 ft) thick. The upper tongue is present east of Kenilworth and contains beds of facies I, II, III, and IV that are 3, 2.5, 3, and 6 m (10, 5, 10, and 18 ft) thick, respectively. These thin-sheet sandstones formed as a river began dumping sediments over coastal plain sediments. These sediments were then reworked and distributed by longshore currents. Progradation of the new delta formed another extensive delta plain. This progradation was likely rapid, as few laterally extensive sandstones occur in the Helper area. Deposition of a second sandstone apparently drowned the swamps before thick peat could accumulate.

Mudstone member 4. A thick section of coastal plain rocks accumulated on and behind or lateral to the Sunnyside delta (figs. 18 and 24). This mudstone resembles underlying mudstones, and merges with mudstone member 3 beyond where the intervening Sunnyside Sandstone pinches out in Willow Creek Canyon and to the west. Mudstone member 4 is 120 m (360 ft) thick near Kenilworth, and thickens to about 70 m (210 ft) thick in Alrad Canyon. This mudstone is an important coal-bearing unit in the Deadman Canyon Quadrangle to the east (Anderson 1978, Nethercott 1986), but contains no laterally persistent coals in the Helper Quadrangle. Coal that

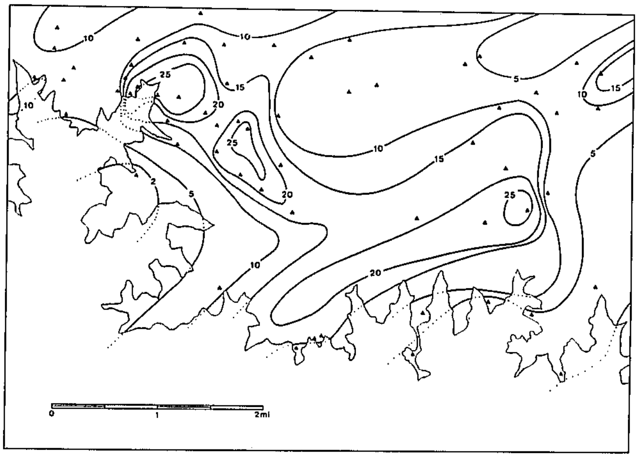


FIGURE 25.—*Isopach of the Kenilworth coal seam in the upper half of the Helper Quadrangle. Areas of thinned coal likely represent effects of fluvial channelling. Coal trends suggest that paleoshorelines ran northeast–southwest. Thickness is in feet, triangles indicate data points, and the thin line represents the coal outcrop.*

formed over the Sunnyside delta plain is equivalent to lower Sunnyside coal in the Tavaputs Plateau to the east. Coal seams of this interval within the quadrangle are the Lower Sunnyside (sometimes called the Castlegate H) and G seams. The Castlegate G seam is locally thick around Willow Creek Canyon, and the H seam is thickest east of Cordingly Canyon. These coals formed in the prograding coastal plains landward of the Sunnyside delta.

Interpretation of the Blackhawk Formation. Several authors have discussed regional depositional relationships of the Blackhawk Formation. Young (1966) proposed that sandstones of the formation represent prograding barrier beaches. Lagoons that formed behind these barriers filled in and supported extensive coal swamps. Balsley (1982) presented evidence that the Blackhawk Formation resulted from a wave-dominated deltaic system. Facies of wave-dominated deltas are similar to those of nondeltaic, prograding barrier beaches, and distinction between the two is dependant on regional considerations. The Sevier orogenic belt shed clastic debris eastward into the foreland basin occupied by the Interior Seaway during Campanian time. Cretaceous floras indicate that this region experienced a warm-temperate to subtropical, seasonal climate (Parker 1976, p. 114). Large complex river systems never developed because of short distances from within the orogenic belt to Cretaceous shorelines, but numerous smaller streams flowed off the uplands and emptied into the Mancos Sea. The high regional slope contributed to a microtidal coastline that minimized tidal effects and maximized wave energy. Heward (1981, p. 236) defined a microtidal coast as one that experiences a 0–2 m tidal range. Microtidal coasts tend to be wave and storm dominated (Coleman 1976, p. 76). Abundant sediment supply, steep regional gradient, latitude, and waves combined to create wave-dominated deltas where rivers dispersed their sediment.

Longshore processes controlled sediment distribution as indicated by distribution of the four major facies of the Blackhawk Formation (figs. 5 and 6). Beds of facies I accumulated near the shale-sand transition zone of the prodelta-marine basin margin. Facies II beds formed the lower shoreface of the delta, or that zone where flow regimes exceeded those of facies I yet were still below normal wave base. Hummocky bedding (Swift and others 1983) suggests that this layer, however, was often scoured by deeper-reaching storm waves. Facies III is dominated by horizontal laminations of trough cross-sets, which indicate regions of high flow in the upper shoreface. These cross-sets reveal the effect of longshore currents that constantly swept the coastline. Cross-sets show currents trended southwestward (Balsley 1982, p. 103) and indicate that the Cretaceous shorelines trended approximately north 60° east. Fluvially dominated facies III beds accumulated near the river mouth, such as those observed in the Spring Canyon and Panther Sandstone Members. These gently sloping, cross-bedded, and poorly sorted sandstones accumulated directly adjacent to the river mouth and grade laterally into well-sorted sandstones away from the focus of sediment input where fluvial influence decreased and longshore currents predominated. Fluvially dominated facies III beds help pinpoint river mouths that were the point beginning of sediment dispersal.

Beds of facies IV are composed of gently dipping planar sets, which formed seaward-sloping sandy beaches. Thin horizontal- to landward-dipping units occasionally overlie rocks of facies IV. These landward units represent washover fans. The process of beach aggradation played a major role in forming extensive beach ridge topography, and these ridges protected earlier ones and swamps from storm invasion (fig. 10).

Abundant sediment supply resulted in coastal progradation as longshore drift accreted sandstone sheets in front of former shorefaces. This accretionary beach ridge system produced a rolling topography upon which extensive coal swamps flourished. These rolls are pronounced in the mines near Helper, with average lengths of rolls approximately 30–35 m and amplitudes of 1.5–2 m. Such spacing of beach ridges correlates closely with modern analogs, similar to that of the Grivalva delta (Psuty 1967). Beach ridges adjacent to river channels are more numerous, closely spaced, and lower than those at greater distances from the river mouth (Psuty 1967). Waves reworked the sediments transported by the river and

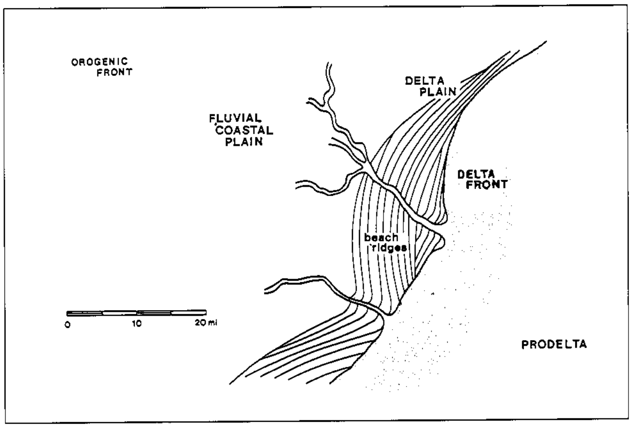


FIGURE 26.—*Model representing the probable configuration of wave-dominated deltas that lined the coast during deposition of the Blackhawk Formation.*

developed an arcuate delta surface that was composed primarily of beach ridges (fig. 26).

Deltaic deposition of the Blackhawk Formation helps explain its cyclic nature wherein portions of the delta became submerged following periodic river diversions on the delta lobe because subsidence continued during a time of little deposition, like that discussed by Coleman (1976). Renewed sedimentation eventually followed each period of submergence as a supply of sediment was provided by a distributary again within proximity of the drowned delta platform. Subsidence allowed sediments to accumulate in the foreland basin, but accumulations of the rhythmic sedimentary packages of the Blackhawk deposition probably reflect normal processess of distributary switching on the delta. This explains how the strand plain could remain stable long enough to accumulate thick delta-front sandstones and coal, and then experienced periods of submergence that allowed deposition of marine shale directly on coastal plain sediments. Lesser transgressions are recorded by thin blankets of mudstone containing brackish water faunas that often lie directly on coal beds. Several layers of mudstone, which contain brackish water fossils, indicate that marine waters transgressed coastal plain deposits and suggest that these particular mudstone deposits accumulated nearly at sea level landward of the sandy beach ridges. The mudstone members may have also accumulated at some distance laterally from distributary mouths of the delta where broad, sandy deposits were not well developed. Channels within the upper part of mudstone members are generally smaller and suggest that large river sources were cut off from the area during mudstone deposition. Frequent submergence also helps explain why thick coals never developed in such mudstones, in contrast to thick coal accumulations of other coastal plain sections.

Previous regional studies of the Blackhawk Formation proposed that barrier islands and lagoons controlled swamp and shoreline configurations. Evidence suggests, however, that features of such a shoreline were probably not major factors within the Blackhawk Formation of the Helper area. Coals rest directly on rolling beach ridges without an interval of lagoonal muds. No fining-upward tidal channel deposits (Dickinson and others 1972) replace beach sequences, and washover fans do not disrupt coal sequences. However, river mouth bar deposits and associated distributary channels incise shoreface sandstones. Low sulphur content of the coals indicates deposition in freshwater swamps, and the lack of preserved transgressive facies indicates that river diversion cut off sediment supply (Balsley 1982, p. 145). Submergence followed channel avulsion on the delta, and a renewed sedimentary cycle began after rivers switched again and renewed the sediment supply. These deltaic processes readily explain the cyclicity of the Blackhawk Formation.

Castlegate Sandstone

Castlegate Sandstone forms formidable cliffs in Price Canyon. Exposures to the east (fig. 27). Clark (1928, p. 119) originally designated this distinctive unit as a member of the Price River Formation, but Fisher and others (1960, p. 14) raised the member to formation rank because of its distinctive lithology and areal extent.

The formation is mappable along the eastern margin of the Wasatch Plateau to the west (Hansen in press, Jensen in press, Oberhansley 1980), but pinches out into Mancos Shale near the Utah-Colorado border (Van De Graaff 1972, p. 42; Willis 1986). The massive sandstone is over

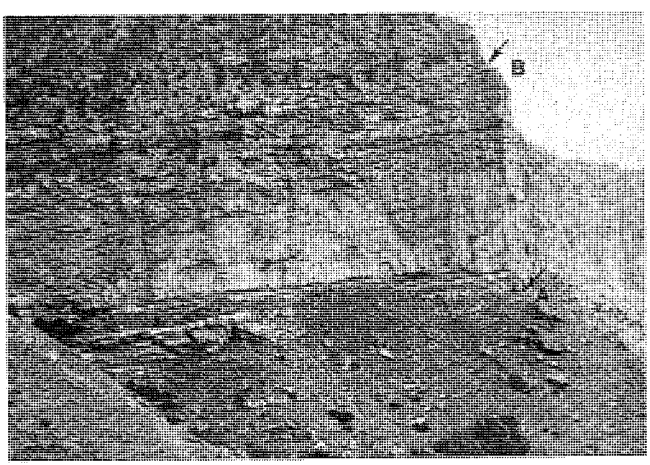


FIGURE 27.—*Outcrop of the Castlegate Sandstone in Price Canyon (NE, NE, section 35, T. 12 S, R. 9 E). Arrow A points to the basal Castlegate contact above slope-forming mudstone member 4 of the Blackhawk Formation. Arrow B points to the contact between Castlegate and Price River beds.*

67 m (200 ft) thick in Price River Canyon, and, as mapped, includes the interval from the base of the cliff to the first break in the sheer wall. The formation boundaries are those originally described by Clark based on the continuous nature of the upper and lower contacts in the Helper Quadrangle. Spieker and Reeside (1925, p. 445) and Lawton (1983, p. 194), however, included a much thicker interval in their designation of the Castlegate Formation. They included the massive cliff as well as rocks of an overlying slope zone and a still younger, but similar, massive sandstone cliff. Rocks of this second, younger interval were mapped, here, as a lower member of the Price River Formation because the slope-cliff package resembles units directly above it.

Thickness of the Castlegate Sandstone varies to some extent throughout the quadrangle. It is 67 m (200 ft) thick in Price Canyon, but less than 50 m (150 ft) thick in the eastern part of the quadrangle. The formation thickens up to 83 m (250 ft) thick on eastward in the Deadman Canyon Quadrangle (Nethercott 1986).

Castlegate Sandstone is coarse to medium grained and quartzose. Weathered outcrops are pale yellow to dark yellowish gray, and fresh exposures are light to very light gray. Coarse sand grains predominate in samples from the lower part of the cliff, but finer sand is dominant farther up in the formation. Abundant carbonized organic debris, kaolinized feldspar grains, and mudstone rip-up clasts occur throughout the formation. Interbedded silty layers interrupt the massive cliff about midway up the formation and form several rhythmic units not seen in the lower part. Rarely does shale or clay occur in the formation, but occasional lenses up to 0.3 m (1 ft) thick were found. Multiple lenticular filling of scoured channels characterizes the formation, and all horizons exhibit extreme lateral variation. Structures within the lenticular channeled deposits consist of cross-bedded sandstone and ripple-marked surfaces. Cross-set and ripple-mark orientations indicate an east-to-southeast direction of transport (Lawton 1983, p. 184; Van De Graaff 1972, p. 42). Structures produced by soft sediment deformation are common throughout the formation. Very thin and highly discontinuous coal layers occur throughout the sandstone. However, one seam in Cordingly Canyon is over 0.6 m (2 ft) thick, but is laterally discontinous. Abundant woody imprints, plant fragments, and even some log impressions are also present.

Spieker and Reeside (1925, p. 45) and Osterwald and others (1981, p. 20) determined that the channelled base of the Castlegate Formation is disconformable. Fouch and others (1983) also documented gaps in the fossil record at the base of the formation. They also concluded that the upper contact with the Price River Formation is conformable and dated the Castlegate Sandstone as Campanian.

Interpretation of the Castlegate Sandstone. Castlegate Sandstone of the Helper Quadrangle was deposited by numerous coalescing, braided streams. These braided streams produced few major point-bars deposits and only minor mudstone, but left behind a blanket of complexly lensing sandstone with only occasional silty horizons. These sandstones are all floodplain channel deposits. Coal swamps grew in stagnant backwaters, but constant shifts in channels restricted their extent.

Increased sediment supply from the west created broad aprons of terrigenous clastic debris that completely overwhelmed shallow-marine environments along the coastline and resulted in the final regression of the Mancos Sea from the Helper area. The coarse Castlegate Sandstone indicates a drastic change as sources and stream energy suddenly increased. Coastal plain sediments of the Blackhawk Formation were channelled and buried as blankets of coarse sand prograded eastward from the source area. Lawton (1983, p. 192) suggested that the coarser sediments resulted from early uplift on the Charleston-Nebo thrust and uplift of the Pavant thrust farther south. It appears that rates of subsidence in the foredeep basin, which had allowed accumulations of thick clastic wedges of the Mancos Shale, may have reduced at about this time, thus hastening the advance of the shoreline to the east.

Castlegate Sandstone includes a wide range of facies in the outcrop belt from the Wasatch Plateau to the Utah-Colorado border (Van De Graaff 1972, p. 38). Spieker (1946, p. 130–132; 1949, p. 70–73) and Van De Graaff (1972, p. 38) believe that the formation becomes part of a red-bed conglomeratic section west of Price Canyon where it is exposed in upper reaches of Spanish Fork Canyon near Red Narrows and has been mapped together with the Price River Formation. Jensen (in press), Oberhansley (1980, p. 76), and Pashley (1956, p. 1786) have mapped the Castlegate Formation as a separate unit in exposures westward on the Wasatch Plateau.

The conglomeratic piedmont facies in the Wasatch Plateau grades eastward into the fluvial facies, represented in the Helper Quadrangle. The formation exhibits delta plain facies east of Green River, near Cisco (Willis 1986). Castlegate Sandstone ultimately grades into delta-front sandstones and wedges out into Mancos Shale in Colorado (Van De Graaff 1972). This resulted in a time-transgressive sheet sandstone, much as underlying Blackhawk Formation, that becomes younger to the east.

Price River Formation

A series of ledges and slopes characterizes the Price River Formation in Price Canyon and nearby areas. Individual lenticular units of massive, coarse-grained sandstone form cliffs, but interbedded units of siltstone and

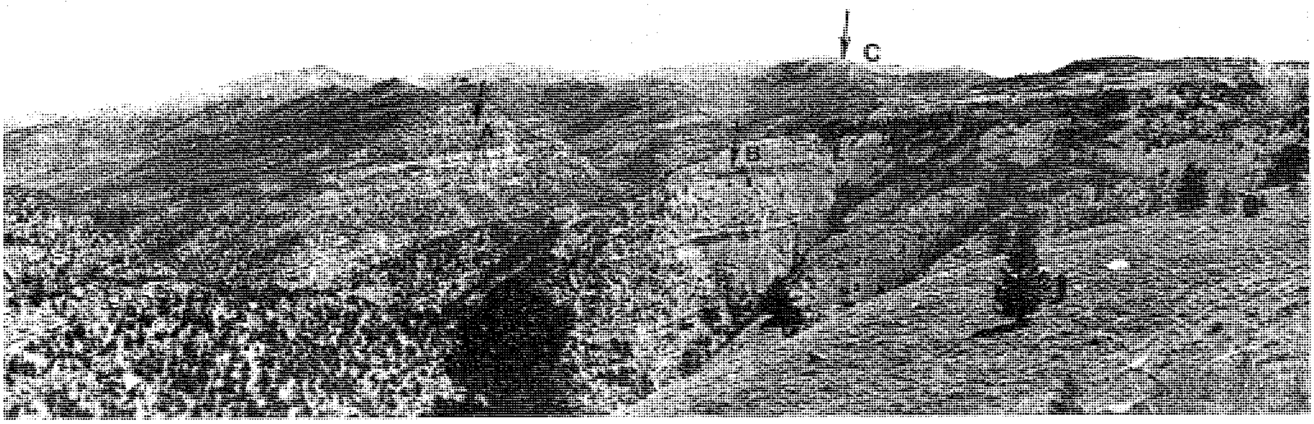


FIGURE 28.—*View to the east–southeast of Upper Cretaceous–Tertiary rocks in the northeast corner of the quadrangle. Slope in the foreground is North Horn Formation (N), arrows A and B point to the contact between Price River (P) and North Horn Formations. Arrow C points to the contact between North Horn and Flagstaff (F) Formations.*

shale form slopes (fig. 28). Four slope-and-cliff pairs occur in the formation in Price Canyon exposures. The lowest slope-cliff zone was mapped as an informal lower member of the Price River Formation because of its persistence throughout the quadrangle. Rocks of this interval were included by Spieker and Reeside (1925, p. 445), Fisher and others (1960, p. 14), and Lawton (1983, p. 194) in the Castlegate Sandstone. The lower member and formation contact was mapped at the first slope break above the massive Castlegate Sandstone cliff (fig. 27). This lower member is 107 m (320 ft) thick in Willow Creek Canyon. This member resembles overlying units and thus was included in the Price River Formation.

An upper informal member was mapped that includes three cliff-slope pairs in Price Canyon, where it is 256 m (770 ft) thick. These sandstone cliffs cannot be traced with confidence much over 2 km laterally because of the lenticularity of individual units. The upper contact of the upper member and the formation was mapped at the point of greatest lithologic change below red beds of the North Horn Formation. This follows the usage of Spieker (1946, p. 131), who divided the Price River and North Horn beds at the level of greatest lithologic change between the thicker sandstone bed of the Price River Formation and the variegated mudstone of the North Horn Formation, and Young's division of the two formations at the first or lowest appearance of red beds in mudstones of the North Horn Formation in Price Canyon (Young 1957, p. 187). Locating the lowest occurrence of red beds of the usually covered mudstone interval is difficult, but sandstone cliffs that crop out directly above the slope of mudstone also have a reddish hue not seen in older sandstones below, which helps locate the contact (fig. 29).

The formation varies greatly in thickness throughout the quadrangle. The greatest measured thickness of the formation, 400 m (1200 ft), appears in Price Canyon, just north of the Helper Quadrangle. It is 386 m (1160 ft) thick in Willow Creek Canyon within the quadrangle, and thins eastward to 110 m (330 ft) thick in Alrad Canyon. Nethercott (1986) reported an average interval of 125 m (375 ft) throughout the Deadman Canyon Quadrangle to the east. The formation thins to 200 m (600 ft) and less west of Price Canyon in the Standardville Quadrangle (Carroll 1987). Formational thinning observed eastward from Price Canyon occurs almost exclusively in the upper member, which measures nearly 257 m (770 ft) thick in Price Canyon, but thins out before reaching the east quadrangle boundary. The lower member is 106 m (320 ft) in Price Canyon, and is 110 m (330 ft) eastward in Alrad Canyon.

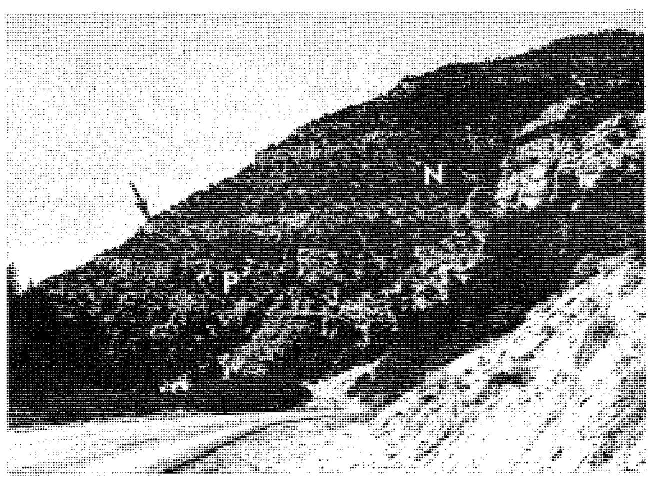


FIGURE 29.—*View westward in Willow Creek Canyon (NW, section 29, T. 12 S, R. 10 E) of the contact between Price River (P) and North Horn (N) Formations. Slopes and outcrops of the North Horn generally have a reddish hue.*

Spieker dated the Price River Formation as late Montanan age, and stated that upper units of the formation are likely of early Lancian age (1946, p. 131).

The Price River Formation is a thick conglomerate unit with a deeply eroded, unconformable upper surface west of the Wasatch Plateau (Osterwald and others 1981, p. 20). The basal contact is conformable with the Castlegate Sandstone in the Helper Quadrangle, and the upper contact passes conformably and gradationally upward into the North Horn Formation.

Lower Price River member. The cliff-slope pair of the lower Price River member maintains a fairly constant thickness of about 330 m across the quadrangle. Individual units within the member are highly lenticular, however, and change rapidly over short, lateral distances. The overlying cliff unit is about 10 m (30 ft) thick in Price Canyon, but is 87 m (260 ft) thick eastward in Alrad Canyon to the east. The underlying slope does just the opposite and thins eastward within the quadrangle and helps maintains the fairly uniform thickness of the overall member.

Fine mudstone, siltstone, and shale of the lower Price River member form the laterally persistent basal slope above the Castlegate Sandstone. Details of the slope's composition are obscured by slope wash and talus, but roadcuts occasionally expose the nonresistant rocks. Organic debris occurs throughout shale, mudstone, and siltstone of the section. Numerous thin coals become increasingly abundant near the base of the member. Occasional lenticular channel-fill sandstones and silty and sandy ledges that crop out exhibit thin bedding. Current direction measurements made by Lawton (1983, p. 185) indicate that streams that deposited these sediments had a general eastward flow.

The cliff interval in the lower Price River member is composed of poorly sorted, fine-grained, grayish orange sandstone. The sandstone is 80% quartz and 20% feldspar grains. The sandstone is trough cross-bedded, and bedding planes are often interrupted by coaly zones. A much thicker sandstone interval is interbedded with black shale and siltstone eastward in Alrad Canyon (fig. 30). Light-colored sandstones of the interval have a sugary appearance, coarsen upward, and contain above 80% quartz grains with feldspar and minor amounts of chert. Individual sandstone bodies at the base are around 8 m (25 ft) thick, but are very lenticular. Siltstone interbeds predominate halfway up through the member, but a 32 m (65 ft) thick, light gray sandstone body, which persists laterally across the quadrangle, constitutes the top of the member. This sandstone coarsens upward. It is also heavily bioturbated and trough cross-bedded. The upper surface of this sandstone is also the boundary between the Price River Formation and the overlying North Horn Formation eastward of Alrad Canyon because the upper Price River member pinches out near there.

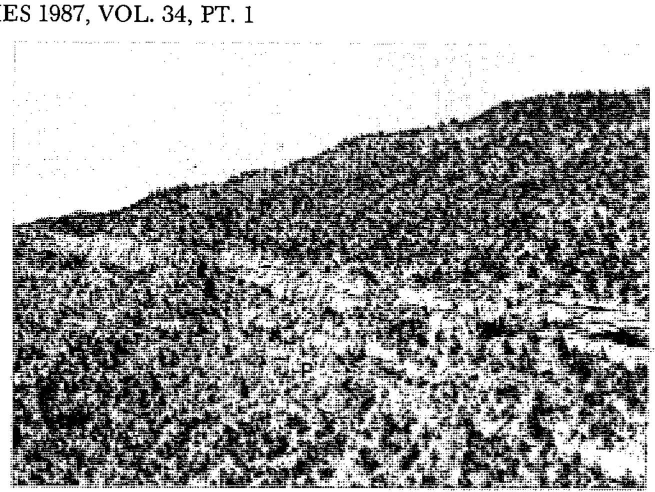


FIGURE 30.—*View of the contact between Price River (P) and North Horn (N) Formations in Alrad Canyon (SE, SE, section 1, T. 13 S, R. 10 E). Arrow points to the contact that occurs at the top of the lower Price River member where the upper Price River member has pinched out in eastern exposures in the Helper Quadrangle.*

Upper Price River member. The upper Price River member consists of sheetlike sandstone bodies that appear to be continous (fig. 29). Attempts to trace individual sandstone cliffs were not successful, however, because the sheets are actually quite lenticular over distances of 3 km. The sandstone bodies, which range from 10 to 30 m thick, are each separated by a slope formed by less resistant, fine-grained sediments.

The resistant sandstone is generally very light gray and commonly very coarse grained. It is channelled and trough cross-bedded, with intervals of horizontal bedded units that usually occur near the top of a sandstone cliff. Individual units coarsen upward, and both upper and lower contacts of the sandstone cliff are sharp. Occasionally, large, channelled-out areas are filled with wedges of coarse-grained sandstone. Thin to medium-bedded units appear within the smaller cut-and-fill channel deposits that make up much of the member. Minor carbonaceous shaly breaks disrupt the ledges near the top of the member. Ripple marks are occasionally present on upper sandstone surfaces. Current directions measured by Lawton (1983, p. 190) consistently indicate a northeastern flow.

Interpretation of the Price River Formation. The Price River Formation represents deposition of coarse and fine clastic sediments by low-sinousity, braided stream systems. Fouch and others (1983) speculated that coarse deposits of the lower member were a result of uplift of proximal thrust belts. Movement on the Charleston-Nebo thrust may have exposed the conglomeratic Indianola Group that supplied coarse, quartzose sediment during the flood of sediment off the Sevier uplands in western and central Utah. The upper member of the formation was likely deposited in a lower alluvial plain setting by numerous coalescing streams as the uplands of the Sevier thrust continued to wear down. Fine-grained sediment collected in floodplains as overbank deposits during floods or as stream energies waned during seasonal changes. Lenticular, wedged-shaped sandstones may have been deposited as point-bar deposits by slightly meandering streams. Streams flowed generally eastward during deposition of the lower member, but gradually began to flow northeast during deposition of younger Price River deposits, when basement uplift initiated movement of the San Rafael Swell southeast of the Helper area.

Eastward thinning of the Price River Formation in the Helper Quadrangle documents a different style of deformation that began during waning stages of Sevier orogenic activity to the west. Broad upwarps, likely controlled by basement faults (Davis 1978), disrupted earlier drainage and caused extensive erosion of Cretaceous deposits throughout the region (Lawton 1983, p. 196). Fouch and others (1983) indicated that intense bleaching and limonitization of the top of the formation characterizes a disconformable surface throughout the region. Such widespread bleached units were not observed in the Helper Quadrangle. Locally, growth of the San Rafael Swell diverted drainage to the northeast and caused eastward thinning of Price River deposits (fig. 31). Price River deposits were thicker off the flanks of the uplift. Differential deposition on the flanks of the contemporaneous uplift caused beds of younger, upper Price River units to be thicker in western exposures and to onlap lower and older Price River beds eastwardly in the Helper Quadrangle.

TERTIARY SYSTEM

North Horn Formation

The North Horn Formation conformably overlies the Price River Formation and is a thick section of interbedded limestone, red claystone, and lenticular sandstones in the Helper Quadrangle (fig. 28). The formation is 670 m (2010 ft) thick in Price Canyon, north of the Helper Quadrangle, but thins to 350 m (1055 ft) near the eastern quadrangle border. Here, two informal members of the North Horn Formation are differentiated and include a lower slope-forming member and an upper, more resistant member. The lower member is 222 m (665 ft) thick and grades upward into the 130 m (390 ft) thick upper member in Alrad Canyon.

The lower contact of the North Horn Formation was mapped at the level of greatest lithologic change between the thicker and coarser sandstones of the Price River Formation and the first appearance of variegated mudstone beds (fig. 29). The gradational, but conformable upper contact was mapped at the base of a very persistent, fossiliferous, blue-gray limestone. This limestone forms the base of the Flagstaff Formation and can be traced through the quadrangle and several kilometers eastward into the Deadman Canyon Quadrangle (Nethercott 1986).

Thick sandstone cliffs alternating with shale slopes lie directly above the Price River–North Horn contact in Price Canyon, several miles north of the Helper Quadrangle. These lower beds have thinned greatly where North Horn beds crop out in the northeast part of the quadrangle and are practically gone near the east edge of the quadrangle. Exposures of North Horn rocks in Barn Canyon, section 25, T. 12 S, R. 9 E, north of Castle Gate, indicate that the lower North Horn beds onlap Price River beds in a general southeast direction. This onlap-

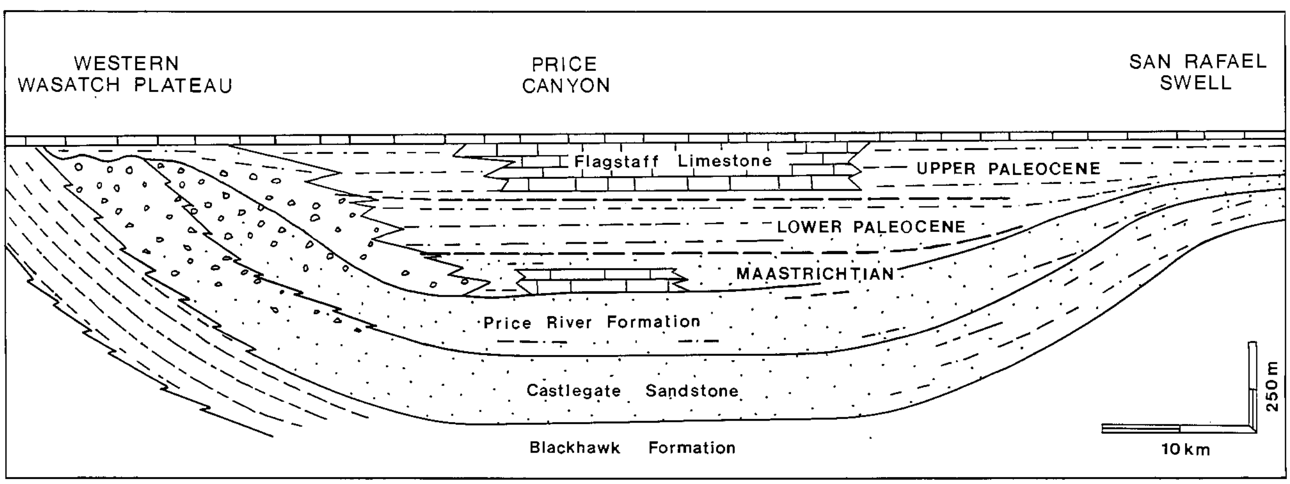


FIGURE 31.—*Generalized regional, east–west cross section through the Helper area. Cross section shows onlapping relationships of Upper Cretaceous–Tertiary rocks created in the Helper area during uplift of the San Rafael Swell, whose structural axis passes to the east of the Helper Quadrangle.*

ping relationship may account for the thinning observed in measured sections to the east.

Fossils of the basal North Horn indicate a Maestrichtian age for these beds in Price River Canyon (Lawton 1983, p. 183). Late Cretaceous dinosaur bones occur elsewhere in lower units of the formation, and upper units contain Paleocene mammal remains (Osterwald and others 1981, p. 22). The Cretaceous-Tertiary boundary occurs near the base of the formation in this quadrangle, based on microfossil assemblages in Price Canyon (Lawton 1983, p. 133). This time-transgressive unit becomes younger to the east.

Lower North Horn member. The lower North Horn member within the Helper Quadrangle forms a gentle slope above cliffs of the Price River Formation (figs. 28 and 30). The slope is developed mostly on red and carbonaceous shale and mudstone that are rarely exposed, except in roadcuts, and is covered by a yellowish gray soil. Occasional thick channel sandstones disrupt the slope. The sandstones are grayish orange and medium to coarse grained. They are horizontally laminated to heavily cross-bedded, with trough cross-sets up to 0.6 m (2 ft) high, and contain abundant rip-up clasts. The sandstone is composed of about 60% quartz grains, 30% feldspar grains, and 10% black chert grains. The quartz and chert grains are subangular and the feldspars are heavily weathered, giving the sandstone an argillaceous texture. Locally abundant rip-up clasts give the sandstone a conglomeratic appearance.

Sandstone occurrence increases upward in the member, and thick, friable ledges 7–10 m (20–30 ft) thick crop out on the shaly slope. These sandstones are usually massive with distinct upper surfaces and have little visible structure. Intervening slopes are interrupted by a few thin sandstone outcrops.

Upper North Horn member. A distinctly steeper slope characterizes the upper North Horn member (fig. 31). Limestones containing abundant freshwater fossils first appear in this interval. The base of this member is usually covered, but numerous lenticular channel-fill sandstones crop out in the member. An overlying interval 33 m (100 ft) thick contains thick, cross-bedded sandstone interbedded with discontinuous clay-limestone conglomeratic beds, fossiliferous limestones that contain reedlike plant fragments, and siltstones. The upper 10 m (30 ft) of the member is composed of very silty, fossiliferous limestone beds that are divided by siltstone interbeds. Fossils collected include whole and broken freshwater gastropods and bivalves. A small bone fragment was found.

Interpretation of the North Horn Formation. Post-Campanian rocks transgressively overlie Price River beds throughout the region (Spieker 1946, p. 133). North Horn sediments filled in the structural basin created by overthrusting in the west and the arching of the San Rafael Swell (fig. 31), whose structural axis passes northward east of the Helper Quadrangle (Lawton 1983, p. 196). Varying regional thicknesses of the North Horn Formation and the eastward thinning observed in the Helper Quadrangle indicate that uplift of the San Rafael Swell was contemporaneous to deposition of the formation.

Rocks of the lower North Horn member in the quadrangle were floodplain deposits. Massive sandstones are likely channel-fill deposits of meandering streams, and fine-grained rocks are overbank deposits. This floodplain was in close proximity to lacustrine settings because of the increasing occurrence of freshwater limestones upward in the formation. The upper member was deposited within a mixed fluvial and lacustrine environment. Sandstones represent fluvial channels and lake-margin sands, and silty limestones indicate freshwater-lake and lake-margin deposition.

Flagstaff Formation

Only the lower part of the Flagstaff Formation has been preserved in the Helper Quadrangle. The formation is about 87 m (260 ft) thick in quadrangles adjacent to the Helper Quadrangle (Anderson 1978, Nethercott 1986), but only the lower 67 m (200 ft) occurs in this quadrangle. This resistant formation caps a dip slope along the south side of Emma Park, between the upper Book Cliffs and the Roan Cliff escarpment (fig. 28). The Flagstaff Formation grades conformably upward and intertongues with the lower Colton Formation in exposures to north of the quadrangle. The term Flagstaff Formation has been used rather than Flagstaff Limestone, as used at the type section (Spieker 1946, p. 135), because of high percentages of interbedded mudstone and sandstone here as compared with that of the type section. Others (including Gilliland 1951, p. 25, 26; La Rocque 1960; McGookey 1960, p. 596; Runyan 1977, p. 71; Sperry 1980) have used the term Flagstaff Formation to describe Tertiary lacustrine units similar to those found in the Helper Quadrangle.

A persistent, medium gray limestone, up to 2 m (7 ft) thick, marks the base of the Flagstaff Formation. Lime, mudstone, and grain-supported carbonates, calcareous siltstone, and sandstone erode to form a steplike slope (fig. 32). Red claystone and siltstone form colorful slopes between ledges of lenticular channel sandstone and fossiliferous limestones. The sandstones are massive and exhibit cross-bedding and cut-and-fill structures. The sandstone is composed of medium- to coarse-grained quartz. Limestones are dark gray, micritic, and contain abundant gastropods, pelecypods, and ostracods. These freshwater fossils are common throughout equivalent rocks in the region (La Rocque 1960, Nethercott 1986, Osterwald and others 1981).

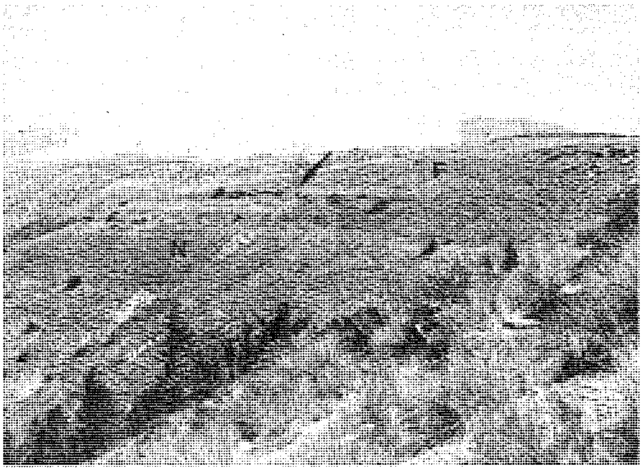


FIGURE 32.—*View northeastward of North Horn (N) and Flagstaff (F) Formations (SW, SE, section 34, T. 12 S, R. 10 E). Arrow points to the contact that occurs below a persistent limestone bed.*

The Flagstaff Formation in the Helper Quadrangle was deposited on a lake-margin carbonate flat during middle-to-late Paleocene time (Ryder and others 1976, Stanley and Collinson 1979). Sperry suggested that open-lake conditions existed during deposition of the formation (1980, p. 166). Subaerial exposure and fluvial channelling indicate that the freshwater lake fluctuated and deposited interbedded nearshore carbonates and fluvial sediments. Deposition occurred in a basin created by downwarping during middle-late Paleocene time off the flanks of the San Rafael Swell. The lake was bounded by structurally high remnants of the Sevier thrust plate and likely overlapped the arch of the San Rafael Swell (fig. 31).

QUATERNARY DEPOSITS

Pediment Gravel

Broad sheets of gravel veneer pediments cut on Mancos Shale below the Book Cliffs in the quadrangle (fig. 2). The Quaternary pediment gravel ranges locally from 5 m (15 ft) up to 17 m (50 ft) thick. Thickest deposits occur near the base of the cliff. The retreating Book Cliffs shed pebble-to-boulder-size gravels, although some blocks up to 3 m (10 ft) across occur locally. The gravels have a poorly consolidated to well-cemented matrix of sand and silt. The sediments have a reddish orange color, similar to the clinkered sandstones of the cliffs. Crude channels appear in the deposits, and semirounded clasts outline individual channels. Most of the fragments are angular and were derived from talus at the base of the retreating cliffs. Minor streams and sheet floods deposited finer-grained sediments and leveled the pediment surface.

West of Price River, dissected pediments extend downward almost to the river. Heavily dissected pediments form high plateaus west of Helper and become less dissected eastward. Pediment gravels lap onto the cliffs in eastern exposures and sweep down into the valley as broad uninterrrupted sheets. The average slope of the pediment surface away from the cliffs is 3 degrees.

Extensive erosion has beheaded pediments around the mouth of Price River Canyon and west of Kenilworth. There are three primary pediment levels within the boundaries of the quadrangle, along with many intermediate levels that formed during adjustment of the drainage of Price River. The lowest level is the most widespread. The middle level is less widespread and is generally 53 m (160 ft) topographically higher than the lowest level. The highest level occurs only in the eastern portion of the quadrangle and lies about 67 m (200 ft) topographically higher than the middle level. It usually occurs as a small isolated remnant that is surrounded by lower pediment levels.

Price River now flows more than 200 m (600 ft) below the level of the highest pediment surface. The widespread lowest pediment surface is being cut by numerous channels that have exposed underlying Mancos Shale in deeper washes.

Response to adjustments of the Price River drainage system likely caused the development of the numerous pediment levels so prevalent in the region. Rich (1935, p. 1013) suggested that the different levels resulted from climatic changes, regradation of the pediment following slope retreat, and possible tectonism. Carter (1977, p. 714) proposed that the pediments were formed by valley cutting and widening by stream erosion with the different levels formed by stream capture followed by aggradation and subsequent regradation and best explains the pediment features observed in the Helper Quadrangle.

Loess Deposits

Thin veneers of reddish brown loess cover portions of pediment surfaces east of Price River in the Helper Quadrangle. These windblown sediments blanket only topographically lower pediment levels. Loess deposits may be up to 2 m (6 ft) thick locally, but average 1 m (3 ft) thick and thin toward the edge of the pediment level. The loess is composed of frosted, subrounded quartz grains with a reddish coating of iron oxide, and 5% to 10% of the grains is medium-grained sand; 50% to 60% is fine- to medium-grained sand; and the remaining 20% or more is silt. Occasional dark chert or heavy mineral grains may also be present. Bedding structures have been destroyed because vegetation has deeply rooted into the loess.

The loess is likely equivalent to windblown sediments described by Huff and Lesure near Blanding and Monticello, Utah, and Dove Creek, Colorado (1965, p. 44), or to

Pre-Wisconsin glacial deposits in the Colorado Plateau described by Hunt (1956, p. 35). Biggar and others (1981) described loess in the Paradox Basin that may also be equivalent to Helper Quadrangle loess. Loess units are difficult to correlate and date in south central Utah because they are widely scattered and contain few datable materials. Most workers belive that placement of the windblown units dates between 30,000 and 10,000 years ago, or during pre-Wisconsin or Wisconsin time.

Occurrence of the loess on only lower pediment surfaces implies that although the loess may have blanketed the quadrangle as an isolated event, it was preserved only in more protected areas where erosion has not yet stripped it away.

Alluvium, Colluvium, and Slope Wash

Recent alluvial deposits range from fine clay to boulders. These deposits flank the Price River and its tributaries and create a wide swath along the west edge of the quadrangle. Thin alluvial fingers line minor streams that flow off the Book Cliffs. Constant adjustments of the Price River have not allowed extensive alluvial deposition.

Talus deposits cover steep slopes below most sandstone outcrops in the quadrangle. The colluvial slopes often obscure Mancos Shale intervals and bedrock units at the base of the Book Cliffs.

Slope wash generally coats steep dissected margins of pediment levels and often blankets broad valley exposures of Mancos Shale. Thin sheets of slope wash consist of poorly consolidated clay or silt and obscure much of the bedrock in the lower part of the quadrangle. Much of such slope wash originates from eroded Mancos Shale and is deposited by running water not confined to stream channels (Witkind 1979). These deposits, as well as talus deposits, were not mapped separately.

STRUCTURAL GEOLOGY

A remarkably uniform homoclinal dip characterizes the structure of the Helper Quadrangle, where rocks dip northward off the San Rafael Swell uplift (fig. 2). The average strike trends nearly east–west, and the dips range from 4° in southern exposures to 6° in northern ones. Dips increase slightly from east to west. Structural contours drawn on the top of the Aberdeen Sandstone Member show the structure well (Russon in press).

No faults were observed in the quadrangle, and no major faults are cited in mining reports. Surface subsidence from collapse of mines occurs occasionally.

Laramide deformation uparched the San Rafael Swell beginning in latest Campanian time and continuing into Paleocene time. This marked the end of foreland basin deposition as overthrust deformation diminished west of the Helper Quadrangle when domes and arches began to form over basement faults (Davis 1978). Uplift of the San Rafael Swell resulted in the eastward thinning of contemporaneous deposits in the quadrangle (fig. 31). The Price River Formation dramatically thins from 400 m (1200 ft) thick in Price Canyon to 110 m (330 ft) thick at the east edge of the quadrangle. Sediments rest conformably on top of the Price River Formation and thin eastward from 670 m (2012 ft) thick in Price Canyon to 350 m (1055 ft) thick in Alrad Canyon. Syndepositional thinning on the flanks of the San Rafael Swell, which existed by Maestrichtian time, caused North Horn beds to onlap Price River beds in the Helper Quadrangle.

ECONOMIC GEOLOGY

Coal remains the Helper Quadrangle's most important mineral resource. Abundant remaining reserves could support production for many years to come. Coal-related methane and other hydrocarbon potential might prove to be economical. Building material and water resources will be needed in exploration and production efforts.

COAL

Abundant and accessible coal reserves attracted the mining industry to the Helper Quadrangle as early as 1889. The first mine produced coal from the Castlegate A (Aberdeen) and Kenilworth coal zones, and in 1901 became the largest in the state (Doelling 1972, p. 362). Doelling estimated that mines produced 65 million short tons (59 million metric tons) from the Helper Quadrangle previous to 1969. The coals of the Helper Quadrangle belong to the Book Cliffs Coal Field, which begins west of Price Canyon and extends east and south to Green River. Economic coals of this field all occur in the Blackhawk Formation (Doelling 1972, p. 191).

Numerous mines have produced coal from four important coal horizons within the Blackhawk Formation of the Helper Quadrangle. These four include the Castlegate A or Aberdeen, Castlegate B, Castlegate C east (east of Price Canyon, also includes lateral equivalent, Royal Blue), and Kenilworth (includes Castlegate D) coal. Unmined seams of lesser importance include the Castlegate E, F, G, Gilson, and lower Sunnyside seams. Nomenclature used to define coal horizons has changed through the years as more subsurface data improved correlation (fig. 33).

Coal isopach maps included in this study were constructed using total coal thickness of each seam. This method was utilized to obtain information regarding swamp configuration. Isopachs using United States Geological Survey (1983) guidelines to determine economic reserves will be published by the Utah Geological and Mineral Survey. Analyses of coals, obtained from over 300 previously collected samples (Doelling 1972), indicate that little difference occurs between coals from one bed to the next within the quadrangle. The coal of the Helper area is classified as high-volatile B bituminous. Remaining reserves are estimated to be about 250 million tons in the Helper Quadrangle (Laine Adair, Price River Coal Company, personal communication 1984).

No coal was produced during the period of this study, due to a heavily depressed coal market. Abundant coal reserves promise a bright future, however, when economics allow further development. Further mining will require the redevelopment of portals and haulage routes because of extensive previous mining. Much of the easy coal has been removed, thus the problems must be considered of mining under increasing overburden, extracting thinner seams, and reworking old operations.

Castlegate A coal. The Castlegate A or Aberdeen seam is the lowest coal stratigraphically in the quadrangle. The seam rests directly on thick beach sandstones of the Aberdeen Member throughout most of the quadrangle (fig. 33).

The Aberdeen coal is workable in some locations west of Price Canyon (Carroll 1987), but is best developed in the Helper Quadrangle (fig. 22). Thicker Aberdeen coal occurs near Kenilworth, and the coal thins out west of Cordingly Canyon.

Most of the Aberdeen coal that lies under 500 m or less overburden has been removed. This amounts to about 10% of the total Aberdeen reserves in the quadrangle. However, overburden of 700 m covers much of the remaining coal.

Castlegate B coal. The Castlegate B seam is present predominantly in western parts of the quadrangle, but only occasionally reaches minable thickness. Of minable Castlegate B coal, about 15% has been removed. Remaining reserves lie beneath overburden ranging from 300–500 m.

Castlegate C coal. The Castlegate coal is much more widespread than the Castlegate B seam. It is laterally equivalent to the Royal Blue seam (Laine Adair personal communication 1983) and was mapped as Castlegate C coal. The C seam is well developed between Panther and Willow Canyons and between Price and Willow Canyons. The seam also thickens near Kenilworth. Roughly 20% of the seam has been mined out, and most of the remaining reserves lie under 300–700 m of overburden.

Kenilworth coal. Kenilworth coal has been the most important seam of the quadrangle. It is minable east of Price Canyon and thins east of Price Canyon (fig. 25). Coal up to 9 m thick occurs in the quadrangle. The Kenilworth seam generally lies on a thick beach sandstone.

The Kenilworth seam has been extensively mined. Well over 50% of the coal has been removed (excluding pillars); any remaining coal is under 500 m or more of overburden.

Castlegate D coal. The Kenilworth coal seam splits westward into three seams west of Kenilworth. The top seam is the Castlegate D seam, the middle seam is a thin unminable seam called the C west seam to differentiate it from the C seam east of Price Canyon. The lower seam remains the Kenilworth seam.

The D seam is minable in the area of Price Canyon and is often over 3 m thick northward in Willow Creek Canyon. Only a small percentage of the seam has been mined out, and remaining coal lies under 300–500 m of overburden. A minable seam eastward in Cordingly Canyon, also called the D seam, is probably not laterally equivalent to coal of the D seam in Price Canyon.

Lower Sunnyside coal. Lower Sunnyside coal rests directly on sandstone of the Sunnyside Member. The coal thickness eastward is fairly constant in thickness in northeast–southwest directions, as observed in Aberdeen and Kenilworth coals. Thicknesses above 1 m occur in Cordingly Canyon and thicken farther eastward in Mathis and Alrad Canyons to nearly 2 m. Numerous discontinous coals occur in approximately the same horizon west of Cordingly Canyon, but because of their lenticularity, it is difficult to correlate these westward coals to Lower Sunnyside coal with much certainty. The Lower Sunnyside seam occurs about 50 m above the Aberdeen Sandstone.

Minor coals. Drill holes encounter coal seams in Price Canyon that have been called E and F seams. The G seam is found in Willow Creek Canyon. These coals are very local, but reach thicknesses of 2.5 m or more. E, F, and G beds may be lateral equivalents of Fish Creek, Rock Canyon, or Gilson beds, which are of economic importance in quadrangles to the east (Nethercott 1986). The Gilson seam, of importance in the Deadman Canyon Quadrangle, extends into the Helper Quadrangle, where coal thickness is greater than 2 m in Alrad Canyon. The seam there is approximately 65 m above the Aberdeen Member.

Exploration Model

A definite genetic relationship exists between occurrence of coal and geometries of paleoshorelines and fluvial channels in the Helper Quadrangle. A clear understanding of deltaic sedimentation, provided by rocks of the Blackhawk Formation, could help construct a predictive exploration model useful in Cretaceous coals of the central Rockies. Numerous measured outcrop sections and cored drill holes in the Helper Quadrangle provide data from which cross sections, fence diagrams, and coal isopachs were produced. Upon analysis, three patterns of coal distribution are evident in the quadrangle.

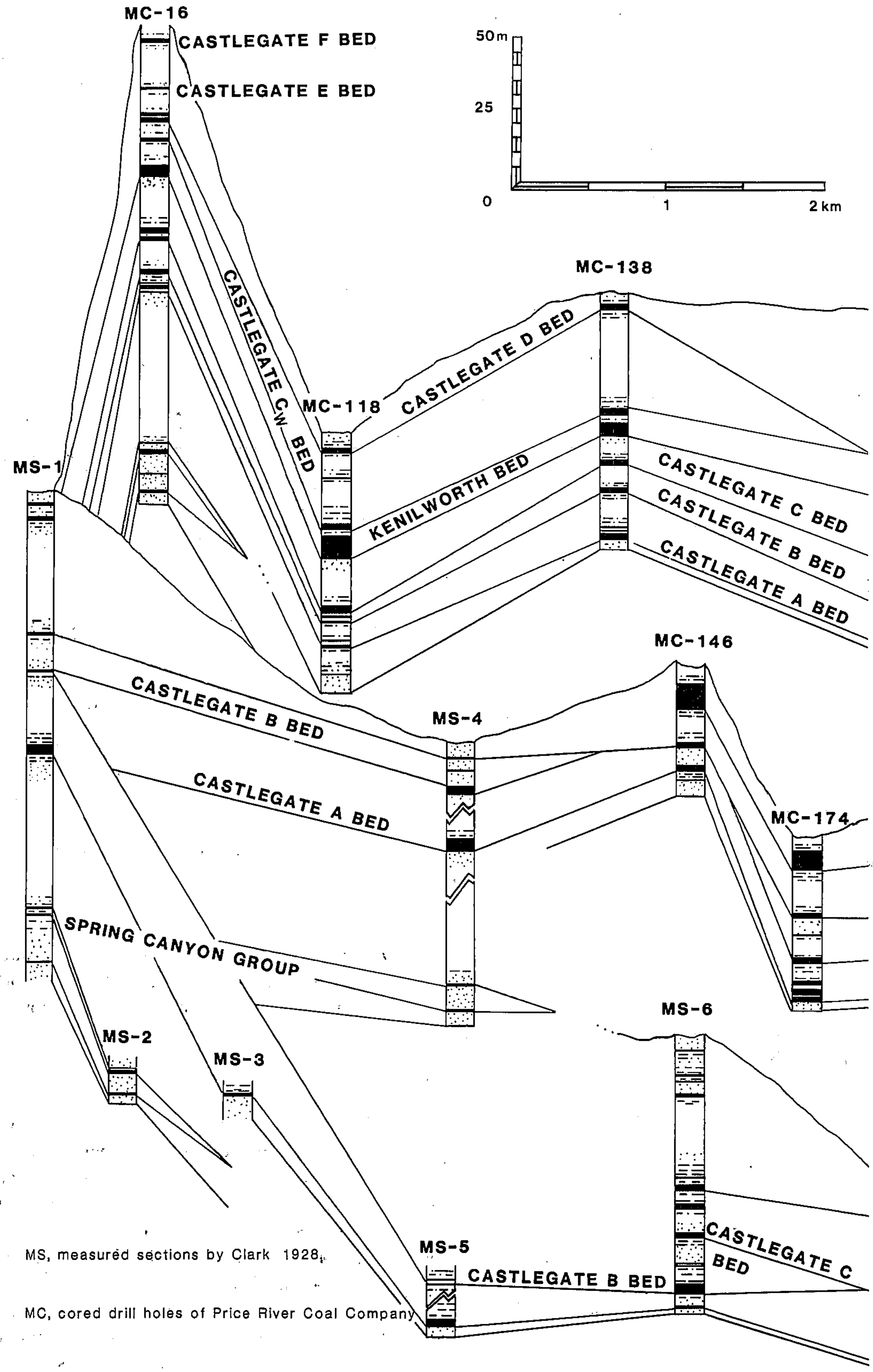
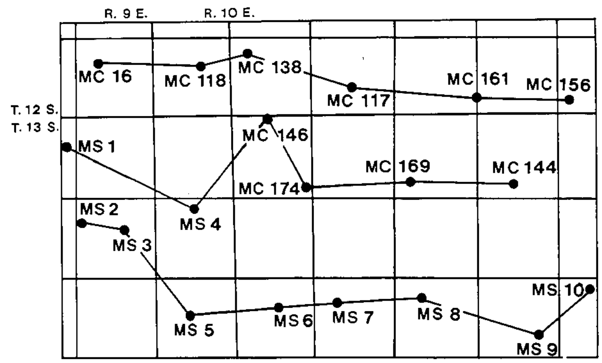
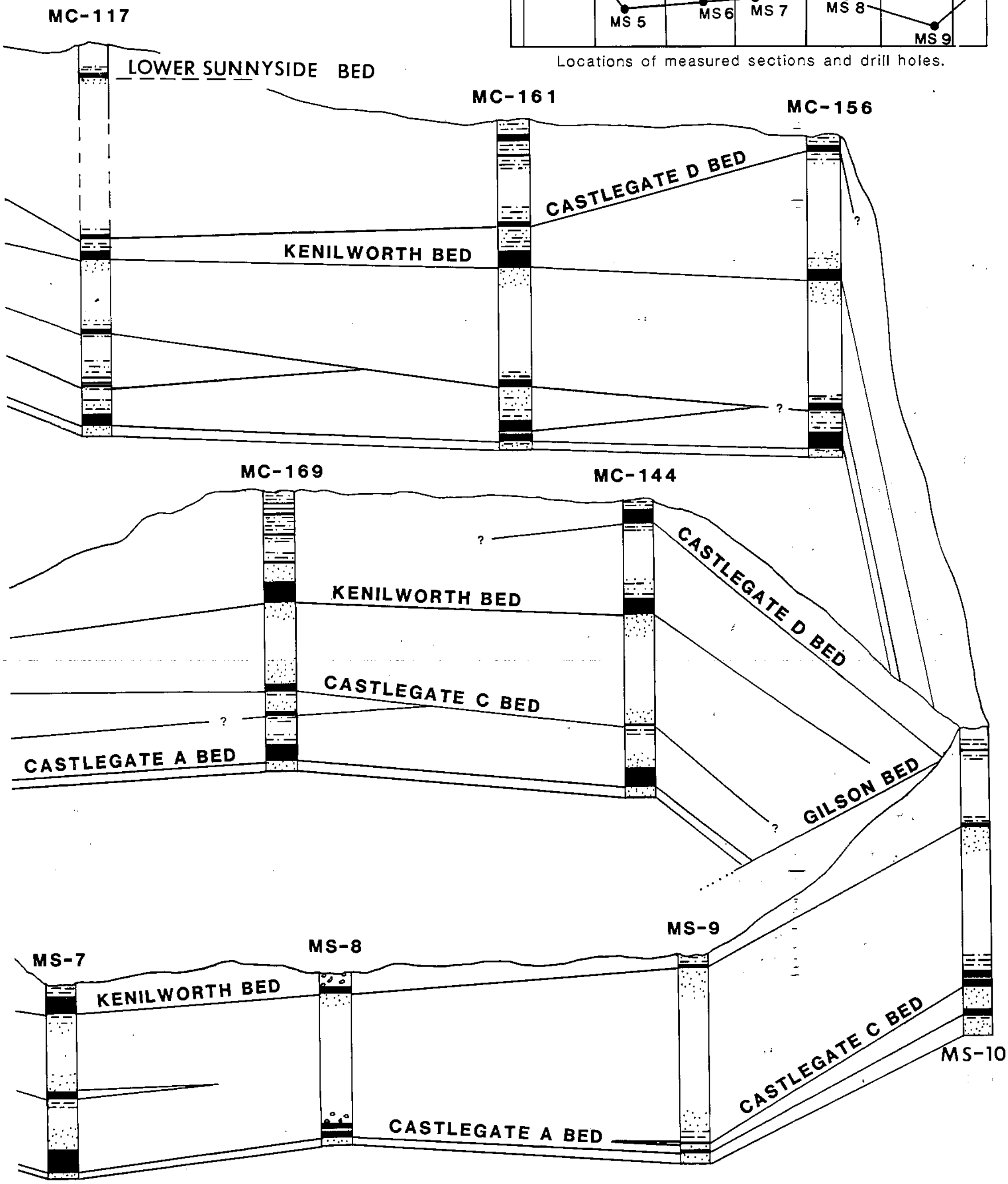


FIGURE 33.—*Fence diagram showing stratigraphic relationships and correlations of major coal beds within the Blackhawk*



Locations of measured sections and drill holes.



Formation in the upper half of the Helper Quadrangle.

1. Coals are thickest when directly underlain by one thin and well-developed beach sandstone (fig. 34A). Apparently, lesser subsidence rates indicated by thinner accumulations of delta-front sand allowed swamp accumulations to keep pace with the subsiding delta platform. As multiple tongues develop, the coal thins quickly. These delta plain coals pinch out rapidly against younger beach-ridge sandstones on the seaward (eastward) margin of the coal. The same seam pinches out gradually landward (westward). Often, coal splits develop westward in the thicker coals as a result of episodic progradation of upper delta plain sediments over lower delta plain coal swamps. Delta plain coals were controlled by shoreline configurations, thus are elongate parallel to the northeast–southwest paleoshoreline in the Helper area. Paleofluvial channels subsequently cut wide swaths in swamp deposits normal to shoreline trends. The Castlegate A, Kenilworth, and Lower Sunnyside seams fit the category of delta plain coal.

2. Thick coals, but of lesser lateral extent than delta plain coals, were deposited in upper delta plain enviroments (fig. 34B). These upper delta plain coals have floor and roof rock of mudstone. These coals were primarily influenced by regional drainage. Streams flowing eastward limited the lateral expansion of swamps and created podlike, elliptical coal deposits. The long axis of thick coal generally parallels the direction of east–west paleodrainage. Coal of the upper delta plain include Castlegate B, C, D, E, F, G, and Gilson seams.

3. Thickest coals of different seams are commonly stacked above each other, as the compaction of vegetation controlled subsequent swamp accumulation (fig. 34C). This occurs primarily in thick delta plain coals. Also, the differential compaction of underlying sandstone versus peat accumulations influenced deposition of overlying sediments. The best example is provided by the Kenilworth seam, which is thickest over areas of greater underlying Aberdeen seam (figs. 22 and 25).

HYDROCARBONS

Two exploratory hydrocarbon wells have been drilled within the quadrangle. The first well, located at NE, SE, SE, section 35, T. 13 S, R. 10 E, bottomed in the Morrison Formation and was plugged and abandoned. A second well, at NE, SW, section 3, T. 14 S, R. 10 E, reached the Entrada Formation and was also plugged and abandoned.

The gentle homoclinal structure of rock in the Helper Quadrangle presents little incentive to explore for structurally related traps. However, potential exists for stratigraphic traps within Mancos, Star Point, and Blackhawk Formations. Porous deltaic sandstones interfinger with rich organic shale of the Mancos Shale and are overlain by marine shale or fine-grained coastal plain sediments (fig. 18). This association of reservoir, source, and cap rocks creates an ideal setting for hydrocarbons. Updip migration (depositionally or structurally) of hydrocarbons from marine shale or coal may result in production potential in the future.

Gas production from coal seams has not been successful in the Helper area, although coal here is classified as gassy (Smith and Mercier 1981). At present, it is not known why the coal in the Helper area has such low desorption rates.

The Blackhawk Formation provides an excellent model that can be applied to hydrocarbon exploration throughout the widespread Cretaceous deltaic deposits in central and northeast Utah. Subsurface and outcrop data reveal the sheetlike nature of individual, porous sandstone tongues, which intricately interfinger with organic shale and coal-bearing rocks (fig. 34). The delta-front sandstones are generally elongate parallel to paleoshorelines. The deltaic sandstones are capped by floodplain or marine shale and create excellent stratigraphic traps. Folding and faulting of these deltaic deposits would greatly enhance hydrocarbon reservoir potential. A clear understanding of deltaic sedimentation, provided by the Blackhawk model, could help predict the occurrence and distribution of similar subsurface sandstones.

BUILDING MATERIALS

Building material will be important in further development and exploration for coal and hydrocarbons in the area. Pediment gravel contains an abundant supply of road metal for construction and improvement of roads.

WATER RESOURCES

No major streams originate in the Book Cliffs in the quadrangle, and perennial streams in upper reaches of the Book Cliffs become ephemeral in lower valleys. Annual rainfall averages 40 cm (16 in) at the north edge of the quadrangle and averages 25 cm (10 in) in the lower valley south of Helper (Wadell and others 1981). Willow Creek joins the Price River, near Castlegate, which flows through the west edge of the quadrangle. These rivers are the only source of surface water in the quadrangle. Much of the subsurface water contains undesirable amounts of dissolved solids, limiting it to industrial use.

SUMMARY

Rock exposures in the Helper 7½′ Quadrangle range from Late Cretaceous to Paleocene age. The upper part of the marine Mancos Shale exposed within the quadrangle is primarily dark gray, organic and silty shale. Two sandstone ledges, the Garley Canyon and Emery Sandstone Members, interrupt the gray slopes of the shale. These two tongues represent deltaic sedimentation in the epeiric Mancos Sea, whose eastern shoreline trended

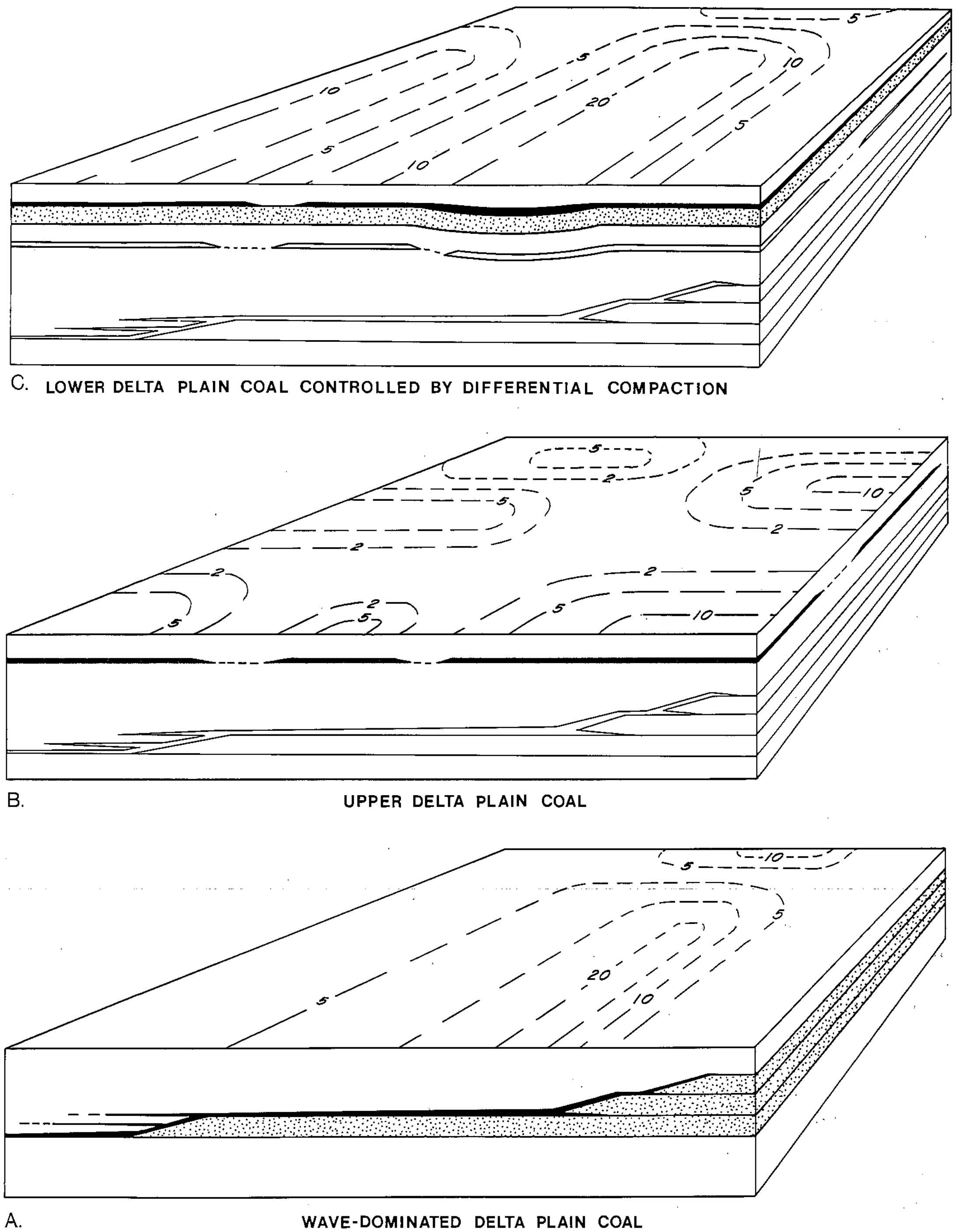


FIGURE 34.—*Model illustrating three major patterns of coal occurrence observed in the Helper Quadrangle.*

A represents coal trends when underlain directly by one well-developed sandstone tongue (with beds of facies I–IV). Delta plain coals are thick, trend paleoshorelines, and pinch out as multiple sandstone tongues develop.

B shows how thinner, upper delta plain coals overlie lower delta plain deposits and were controlled by east-to-west flowing streams.

C illustrates effects of underlying, thick intervals of coal, or peat in earlier stages, on younger, overlying swamp accumulations. Note that thick coal of C overlies thick coal of A.

northeast–southwest in the Helper area. These sandstone tongues indicate the basinward limit of deltaic sedimentation during Campanian time as they both pinch out eastwardly within the quadrangle. Only transitional and lower shoreface facies are present in these sandstones within the quadrangle.

The Star Point Sandstone contains two deltaic sandstone tongues that also prograded eastward into the shallow sea. The Panther and Storrs Members are both made up of lower shoreface and transitional sandstone facies. Exposures of fluvially influenced lower shoreface facies characterize the Panther Member in Price Canyon.

The thick, economically important Blackhawk Formation was deposited along a wave-dominated coastline. Thick sandstone wedges prograded seaward and developed transitional, lower and upper shoreface and foreshore facies. Thick coal developed directly on the undulating beach surface, and overlying fine-grained sediments and thinner coals acummulated as the delta plain prograded seaward.

The Blackhawk Formation contains four sandstone members: the Spring Canyon, Aberdeen, Kenilworth, and Sunnyside Sandstones. Each member develops stratigraphically higher and eastward of the underlying sandstone, resulting in a shinglelike stacking of sandstone sheets that becomes progressively younger to the east. Each sandstone is overlain by a coal-bearing mudstone. The Sunnyside Sandstone pinches out westwardly into mudstones near Price Canyon. Thus, no sandstone divides mudstone members 3 and 4 in this area, and they merge to form a thick coal-bearing section. The Blackhawk Formation resulted from rhythmic progradation of deltaic sediments that forced a halting and final retreat of the Mancos Sea from the area.

Outcrop and subsurface information provide an understanding of deltaic sedimentation necessary to reconstruct swamp configurations responsible for coal deposition. Isopachs of coal seams reveal definite genetic relationships between coal occurrence and sandstone facies, and geometries of shorelines and fluvial channels. Such information helped construct a predictive exploration model useful in Cretaceous coals of the central Rockies. Important coal seams of the Helper Quadrangle include the Castlegate A or Aberdeen, Castlegate B, Castlegate C, Kenilworth, Castlegate D, and Lower Sunnyside seams. Remaining coal reserves in the quadrangle are estimated at 250 million tons.

The delta-front sandstones of the Blackhawk and related formations are also potential hydrocarbon reservoirs, due to their porous nature and because they usually interfinger with organic-rich marine shale, and underlie fine-grained coastal plain sediments. A wave-dominated deltaic model, constructed from information provided by the Blackhawk Formation, can be used to predict the occurrence and distribution of similar hydrocarbon-bearing sandstones in the subsurface.

Deposition of the Castlegate Sandstone came as an eastward flood of coarse-grained sediments off the Sevier orogenic highlands. Braided stream deposition of the Castlegate Formation gradually changed to deposition of the alternating coarse- and fine-grained beds of the Price River Formation by braided and low-sinuosity streams. Early basement uplift of the San Rafael Swell began to influence sedimentation during latest Campanian time and is documented by rapid eastward thinning of younger Price River units. Coarse-grained, fluvial rocks similar to Price River beds form the lower part of the Maestrichtian North Horn Formation and grade upward into dominantly floodplain and lacustrine deposits. These rocks were deposited within internally drained basins created between Laramide-type uplifts and remnants of the Sevier orogenic belt. Eastward thinning is also observed in North Horn rocks in the quadrangle. These rocks were differentially deposited on the flanks of the uplifting San Rafael Swell. An incomplete section of Flagstaff Formation is preserved in the quadrangle. The limestone, shale, and siltstone of the formation were deposited in lake-margin to open lacustrine setting within internally drained basins caused by basement uplifts that continued to move throughout the Paleocene.

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