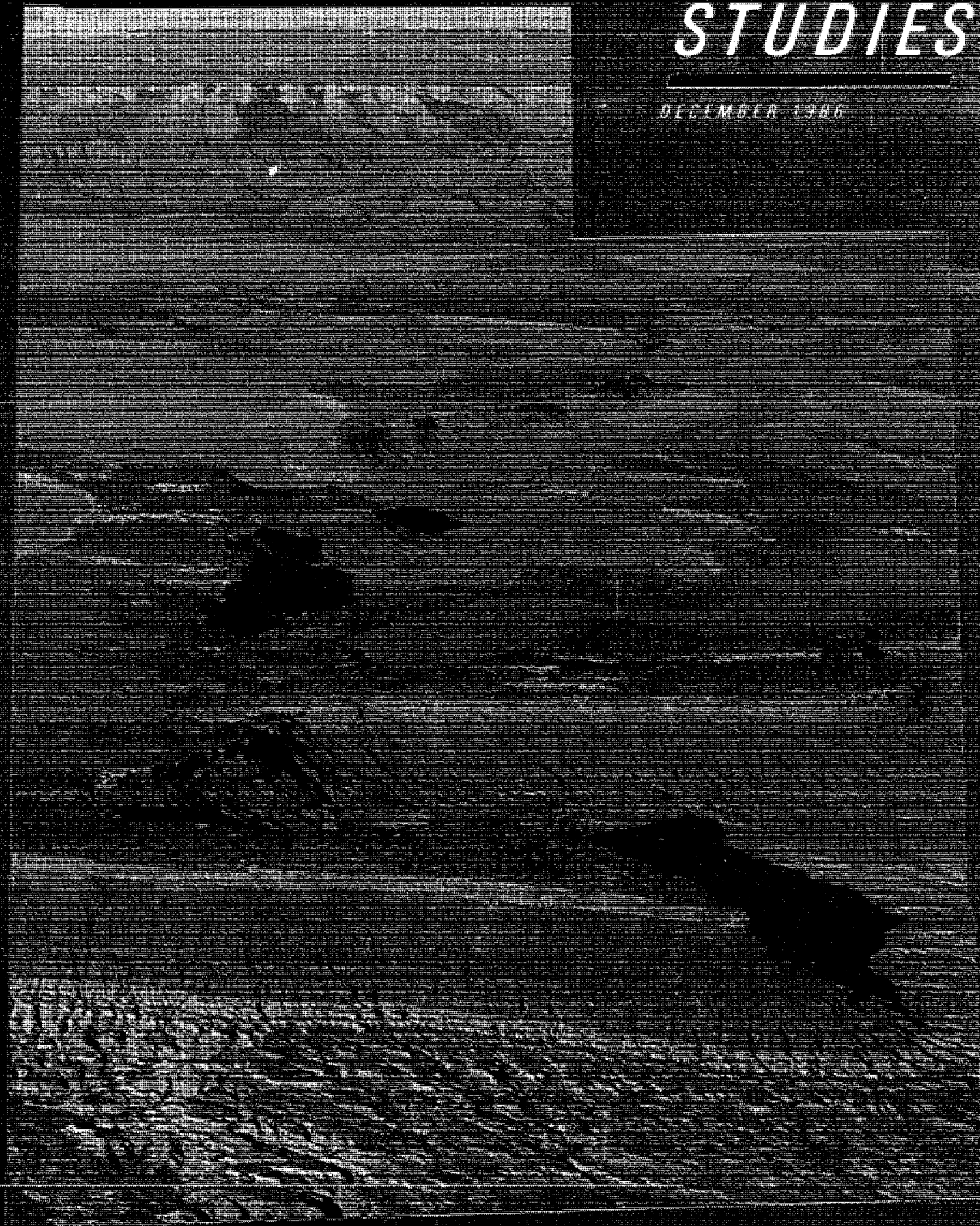


BRIGHAM  
YOUNG  
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# GEOLOGY

*STUDIES*

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# BRIGHAM YOUNG UNIVERSITY GEOLOGY STUDIES

Volume 33, Part 1

## CONTENTS

Tertiary Geologic History of the Slate Jack Canyon Quadrangle, Juab and Utah Counties, Utah .....	Mark E. Jensen	1
Stratigraphy and Facies Analysis of the Upper Kaibab and Lower Moenkopi Formations in Southwest Washington County, Utah .....	John Jensen	21
Geology of the Deadman Canyon 7½-Minute Quadrangle, Carbon County, Utah .....	Mark A. Nethercott	45
Paleocene (Puercan-Torrejonian) Mammalian Faunas of the North Horn Formation, Central Utah .....	Steven F. Robison	87
Depositional Environments of the Tertiary Colton and Basal Green River Formations in Emma Park, Utah .....	James Douglas Smith	135
Geology, Depositional Environment, and Coal Resources of the Sego Canyon 7½-Minute Quadrangle, near Green River, East Central Utah .....	Grant C. Willis	175
Publications and Maps of the Department of Geology .....		209



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Cover: Moenkopi Formation, Southern Utah

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# Geology of the Deadman Canyon 7<sup>1</sup>/<sub>2</sub>-Minute Quadrangle, Carbon County, Utah\*

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## ABSTRACT

The Deadman Canyon 7<sup>1</sup>/<sub>2</sub>-Minute Quadrangle is a major coal-producing area containing rocks ranging in age from the Late Cretaceous Mancos Shale to the early Eocene Flagstaff Formation. The coal-bearing Upper Cretaceous Blackhawk Formation was subdivided for mapping into the Spring Canyon, Aberdeen, Kenilworth, lower mudstone, Sunnyside, and upper mudstone members. Price River and North Horn Formations were each subdivided into lower and upper unnamed members. The contact between the fluvial Price River Formation and fluvial-lacustrine North Horn Formation, as described by previous workers, is difficult to map with confidence. Therefore, the contact was mapped at the top of a prominent sandstone that crops out continuously as a cliff across the quadrangle.

Littoral sandstones of the Blackhawk Formation represent prograding wave-dominated deltas that interfinger eastward with tongues of marine Mancos Shale. Coal-bearing rocks were deposited in associated Cretaceous paralic, delta plains, and coastal plain swamps that roughly paralleled the strandline.

The Gilson, Castlegate "A," Lower Sunnyside, and possibly the Castlegate "B" coal zones reach average coal thicknesses that permit economical subsurface mining operations. Thickness averages for the main coal zones are as follows: Gilson seam 1.5 m (4.9 ft), Castlegate "A" seam 1.1 m (3.3 ft), Castlegate "B" seam 0.8 m (2.5 ft), and Lower Sunnyside coal 1.1 m (3.6 ft). The above averages cover measurements for the entire quadrangle except for the Castlegate "A" and "B" coals that are restricted to the western half of the quadrangle. The Kenilworth (0.7 m = 2.0 ft) and Rock Canyon (0.9 m = 2.8 ft) coal zones show possible potential for future in situ coal gasification and subsurface mining, as future economic conditions permit. More data from exploratory wells are needed to more accurately estimate development potential of these thinner coal zones in the quadrangle.

## INTRODUCTION

The Deadman Canyon 7<sup>1</sup>/<sub>2</sub>-Minute Quadrangle is situated in the Book Cliffs coal field, approximately 16 km (10 miles) northeast of Price, Utah. Development of the Cretaceous coals in the quadrangle is of prime concern. Understanding of the stratigraphy of both coal- and noncoal-bearing rocks, structural geology, and depositional environments will aid in determining coal exploitation potential of the quadrangle.

Early regional studies of the area were focused on stratigraphy and structural geology of the Wasatch Plateau and Book Cliffs. Clark (1928) mapped the geology and made a reconnaissance coal survey from Helper to Sunnyside, Utah. Others have concentrated their studies on the stratigraphy and depositional environments of the

coal-bearing rocks in the Book Cliffs as a whole.

A geologic map (Nethercott 1985) was constructed on a scale of 1:24,000 and published by the Utah Geological and Mineralogical Survey. Five important coal zones (horizons) in the Blackhawk Formation were mapped and measured, both at the outcrop and in the subsurface. Coal isopach and rock interburden maps help estimate coal development potential. Data from coal and petroleum exploratory wells drilled in the quadrangle, combined with outcrop information, were used to construct a structural contour map of the area. Other data collected from measured stratigraphic sections were used to interpret depositional environments of the rocks in the quadrangle.

\*A thesis submitted to the Department of Geology, Brigham Young University, in partial fulfillment of the requirements for the degree of Master of Science, April 1983.

## LOCATION AND ACCESSIBILITY

The Deadman Canyon 7½-Minute Quadrangle is located in the Book Cliffs of Carbon County, Utah (fig. 1). The area is bordered by the Helper Quadrangle to the west, the Minnie Maude West Quadrangle to the north, the Pine Canyon Quadrangle to the east, and the Wellington Quadrangle to the south.

Access into the area is good. Two partially paved roads to coal mines and Utah 53 provide the main access. Numerous unimproved jeep roads also cross the area. Most of the land in the Book Cliffs and Emma and Whitmore Parks north of the Book Cliffs is privately owned. Permission from the owners is required to enter some of the land.

## PREVIOUS WORK

Most previous work in this area has focused on the economic potential of the coal-bearing rocks. Taff (1906) studied the coal field between Sunnyside and Castlegate, mapping only the top and base of the coal-bearing units. Clark (1928) made a detailed study of the geology and economic geology of the Castlegate, Wellington, and Sunnyside Quadrangles in Carbon County, Utah. He described the stratigraphy and general structural geology and published maps of part of each quadrangle from Castlegate to Sunnyside, including Deadman Canyon, on a scale of 1:42,240. Young (1955, 1957, 1966, 1976) studied the rocks of the western Book Cliffs, emphasizing stratigraphy and depositional environments of the Blackhawk Formation. Anderson (1978) mapped and studied the geology and coal resources of the area directly east of the Deadman Canyon Quadrangle. Balsley (1982) studied the stratigraphy and interpreted the paleoenvironments of the coal-bearing rocks of the Book Cliffs of central Utah. Others, such as Osterwald, Maberry, and Dunrud (1981), Parker (1976), Doelling and Graham (1972), studied the economic potential and paleoenvironments of the coal

units in the area. Rich (1935) discussed the origin and evolution of rock fans in and around the Deadman Canyon Quadrangle. Spieker (1946, 1949) described the geologic history of central and eastern Utah. Fisher, Erdmann, and Reeside (1960) studied the Cretaceous and Tertiary formations in Carbon County. Van De Graaff (1972) described the fluvial facies of the Castlegate Sandstone.

## METHODS

Fieldwork was done between late May and late September 1982. Stratigraphic sections were measured with a Jacob's staff. A 12-foot metal tape was used to measure coal sections. Geology and coal outcrops were mapped on aerial photos at a scale of 1:31,000. Data were then transferred to the Deadman Canyon 7½-Minute Quadrangle topographic sheet. Channel samples of main coal seams were collected at various locations throughout the area. Each sample was collected in a plastic bag and sealed with tape. These samples will be analyzed by the Utah Geological and Mineral Survey as part of a subsequent study by their personnel.

## ACKNOWLEDGMENTS

J. K. Rigby served as thesis chairman and H. J. Bissell and J. L. Baer served as committee members. Financial assistance was received from the Utah Geological and Mineral Survey. Michael Glassen and Tower Resources aided me in my subsurface work. Robert Nethercott, Darin Singleton, and Michael Child assisted in fieldwork. Special appreciation goes to my wife, Christie, for her help and support.

## STRATIGRAPHY AND SEDIMENTATION

### GENERAL STATEMENT

Exposed rocks in the Deadman Canyon Quadrangle range in age from Late Cretaceous to early Tertiary (fig. 2). The oldest exposed formation is the Mancos Shale, which is overlain by the Upper Cretaceous Mesaverde Group. Only a partial section of Mancos Shale is found in the area. Star Point Sandstone, Blackhawk Formation, Castlegate Sandstone, and Price River Formation constitute the Mesaverde Group. The younger North Horn Formation is time transgressive and straddles the Late Cretaceous and early Tertiary boundary. Flagstaff Limestone is of Paleocene–Eocene age, and is the youngest Tertiary formation preserved in the area. Quaternary deposits consist of stream alluvium, slope wash, colluvium, and pediment gravels. A possible unconformity is present between the Blackhawk Formation and Castlegate Sandstone in the Deadman Canyon Quadrangle. A major unconformity is found between Cretaceous and Tertiary rocks and Quaternary surficial gravel deposits.

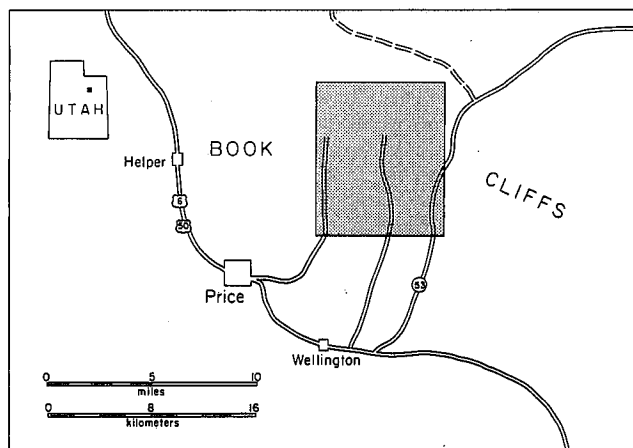


FIGURE 1.—Index map of the Deadman Canyon Quadrangle.

Maximum thickness of rocks studied in the area is approximately 1760 meters. The section from the top of the Mancos Shale to the top of the Flagstaff Limestone thins from west to east, with most thinning occurring in the Blackhawk Formation.

The section as a whole is composed predominantly of clastic rocks including shale, mudstone, sandstone, and siltstone. Major coal seams are found in the Blackhawk Formation. The North Horn Formation and Flagstaff

Limestone contain thin freshwater limestones.

Contacts between the North Horn and Price River Formations were difficult to map. Identification of a mappable North Horn–Flagstaff Formation contact was also difficult. Subdivision of the Blackhawk Formation into members varies from author to author. Nomenclature depended chiefly upon the author's goals and upon the geographic location of his study.

SYSTEM	STAGE	FORMATION	LITHOLOGY	THICKNESS meters (feet)	DESCRIPTION
QUATERNARY	EOCENE	un-consolidated deposits		0-25 (0-75)	alluvium, colluvium, slopewash, pediment gravels
		Flagstaff Formation		86 (280)	Fluvial, lacustrine, mudstone, shale, sandstone, limestone, yellow orange, medium to dark gray
TERTIARY	PALEOCENE				
		North Horn Formation		320 (1040)	Fluvial, lacustrine, mudstone, shale, siltstone, sandstone, limestone, minor conglomerate, variegated yellow orange, gray orange
CRETACEOUS	DANIAN				
		Price River Formation		83 (270)	Fluvial, sandstone, siltstone, shale, medium gray to gray brown
		Castlegate Sandstone		77 (250)	Fluvial, sandstone, minor shale, medium gray brown

SYSTEM	STAGE	FORMATION	LITHOLOGY	THICKNESS meters (feet)	DESCRIPTION
CRETACEOUS	CAMPANIAN	Blackhawk Formation		225 (900)	Littoral, fluvial, sandstone, shale, mudstone, coal, pale yellow orange and light gray
		Mancos Shale (tongue)		40 (120)	Shale, siltstone, medium gray
		Spring Canyon Member		40 (120)	Marine, siltstone, shale, minor sandstone
		Mancos Shale (tongue)		106 (345)	Marine, shale, siltstone, medium gray
		Star Point Sandstone		5-25 (16-80)	Sandstone, siltstone
		Mancos Shale		1540 (5000)	Marine, shale, siltstone, minor sandstone, medium gray and brown gray

FIGURE 2.—Stratigraphic column of rocks in the Deadman Canyon Quadrangle. Main coal zones of the Blackhawk Formation are labeled as follows: Cg Castlegate A; K Kenilworth; G Gilson; R Rock Canyon; S Lower Sunnyside. (Coal thickness exaggerated.)

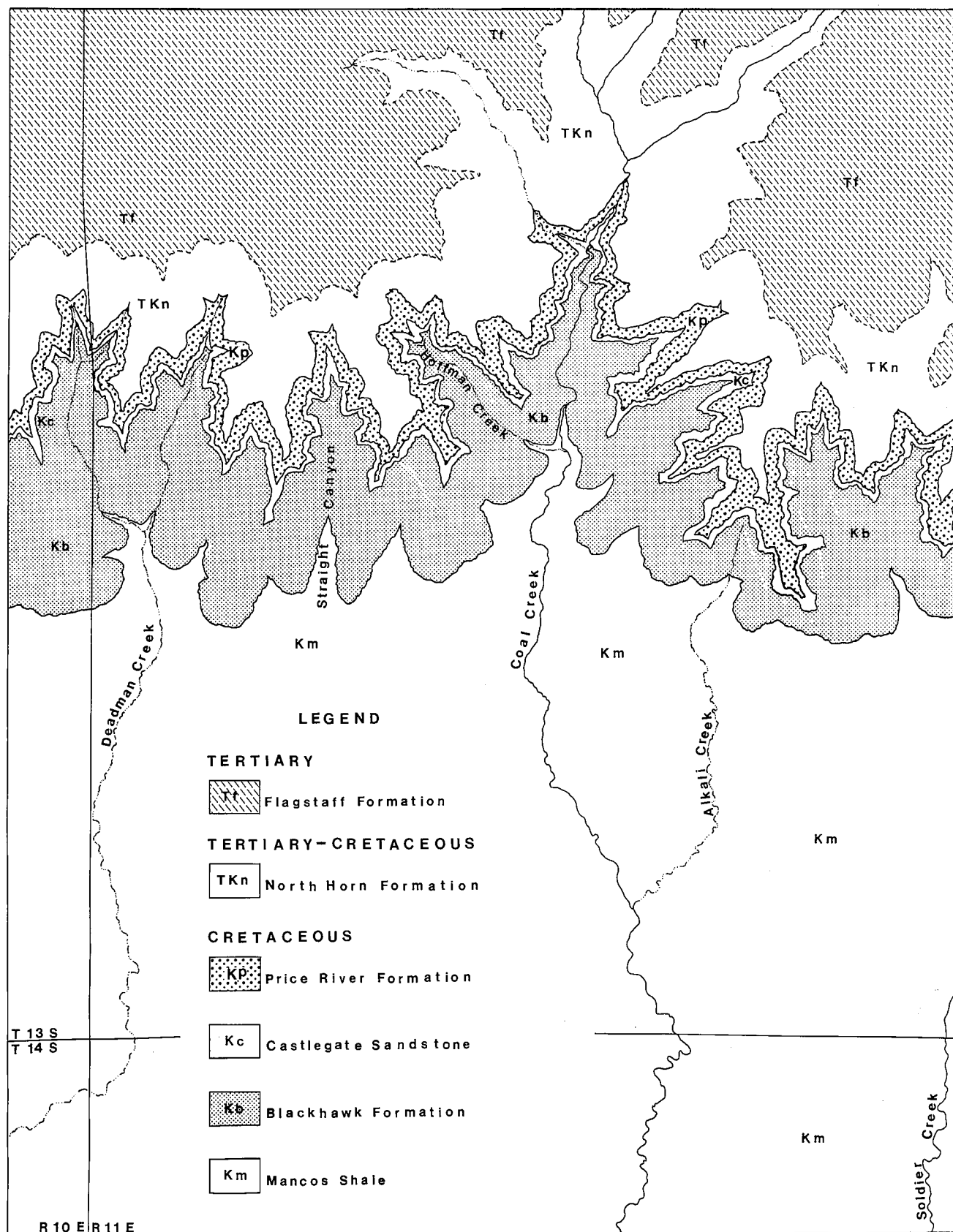


FIGURE 3.—Simplified bedrock geologic map of the Deadman Canyon Quadrangle.



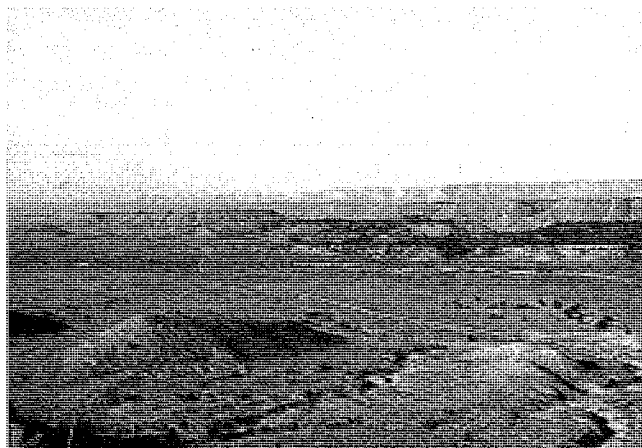


FIGURE 4.—Valley forming Mancos Shale near Coal Creek looking to the southwest from a bluff 1 km east of the old Young Ranch.

## CRETACEOUS SYSTEM

### *Mancos Shale*

Upper beds of Mancos Shale crop out in the lower or southern half of the Deadman Canyon Quadrangle (fig. 3) and are covered with pediment gravels and slope wash. The shale is exposed in steep slopes underneath ledges of protective gravel or resistant sandstones; badland topography is developed in some of these steep slopes. Where not protected by overlying resistant units, the Mancos Shale forms gentle slopes or open valleys (fig. 4).

Generally, the soil formed by weathering of the Mancos Shale is impermeable; therefore, most precipitation on it runs off. For this reason deep ravines or washes cut through the broad valleys formed in the shale. In these washes fresh outcrops of Mancos Shale are exposed. Such exposures have a nodular or botryoidal appearance, typical of massive mudstone or claystone.

Calcareous shale, silty shale, siltstone, sandstone, and minor lentils of limestone (Young 1955, p. 182) are dominant rocks in the Mancos. Fresh colors range from medium gray to bluish gray, whereas weathered slopes exhibit blue or brownish gray colors. Localized lentils of siltstone and sandstone, from a few mm to several cm thick, occur throughout the section.

More resistant sandstone beds hold up minor cuestas or cap knolls of shale. Sandstones range from medium gray brown on a fresh surface to pale yellowish orange on weathered surfaces, are very fine-grained, and occur in beds usually less than one meter thick. Locally these lentils contain high amounts of carbonaceous material. Fragments of wood, up to 8 cm long, occur in some beds.

Sandstone beds tend to be fossiliferous. An echinoderm, ammonoid fragments, and several bivalves were observed. The sandstones are commonly bioturbated;

burrows attain diameters of 0.8 cm. Sandy calcareous concretions that contain cephalopods, bivalves, or other organic fragments also occur in the sandstone and siltstone (Osterwald, Maberry, Dunrud 1981, p. 15).

Total thickness of the Mancos Shale in the Book Cliffs area of Carbon County ranges from 1,432 m to 1,539 m (Clark 1928). In western Colorado the Mancos is about 1,230 m thick. Exposed thickness of Mancos Shale measured at Coal Creek totals nearly 750 m.

The shale intertongues with the Star Point Sandstone and lower Blackhawk Formation. Mancos Shale tongues thin toward the west and the sandstone tongues thin toward the east. Lower contacts of sandstone tongues are gradational, whereas upper contacts are sharp.

Such interfingering results in a stratigraphic rise of the upper boundary of the Mancos from west to east. The upper boundary, therefore, becomes progressively younger toward the east (Young 1955, p. 182). Rocks near the boundary between the Mancos and Blackhawk Formations are assigned an early Campanian age in the western Book Cliffs region (Young 1966, p. 11).

Mancos Shale is believed to have been deposited in a shallow marine environment (Howard 1966a, b, c, Maxfield 1976). Young (1955) stated that sediments of the Mancos Shale accumulated in a marine environment past the mud-sand transition line; however, most of the mud was probably deposited near shore. Lithology and trace fossils, combined with other paleontological evidences, support Howard's and Young's conclusions.

### *Star Point Sandstone*

Three sandstone tongues were originally assigned to the Star Point Sandstone. In ascending order they are the Panther tongue, Storrs tongue, and Spring Canyon tongue. Young (1955, p. 182) redefined the Star Point as consisting of the basal Panther tongue and overlying Storrs tongue. The Spring Canyon tongue was assigned to the Blackhawk Formation.

The Star Point Sandstone occurs in the northern Wasatch Plateau and western Book Cliffs of central Utah. This formation interfingers with the Mancos Shale and pinches out to a feather edge northeast of Wellington, Utah. The Storrs tongue is not recognizable in the Deadman Canyon Quadrangle, for it pinches out about 2 km east of Kenilworth, Utah. Younger Panther sandstone, however, is more persistent and is mappable in the Deadman Canyon area. It thins across the quadrangle, but does not pinch out until it reaches Fish Creek, several kilometers east of Soldier Creek (Anderson 1978, p. 17). Maximum thickness of the Panther tongue is 40 m in the Wasatch Plateau, and ranges in thickness from 24 m to 5.5 m in the Deadman Canyon area. Where not covered by colluvium, the Panther beds form a cliff (fig. 5).



FIGURE 5.—Panther Sandstone looking to the northeast, 2 km east of the mouth of Coal Creek Canyon. The cliff is 14 m high.

The Panther tongue can be subdivided into two lithologic units, a basal interbedded siltstone and sandstone and an upper sandstone. Sandstones of the basal unit are very fine grained, and have a clay and silt matrix that is rich in organic material (Howard 1966a, b, c, p. 27). Primary dolomite is also a constituent in the sandstone (Sabins 1962). Sandstone coarsens upward and becomes finer grained to the east, and bed thickness increases upward in the section.

Fresh color of these sandstones ranges from medium gray or gray brown, and weathered surfaces are medium grayish orange. As the amount of silt increases, the weathered color changes to medium gray.

Siltstones weather medium gray, and are often heavily bioturbated, which gives the rocks a mottled appearance. Rocks of the lower lithologic unit are thin bedded, ripple marked, and commonly exhibit hummocky bedding.

The upper sandstone lithology consists predominantly of fine-grained sandstone. Grains are 90% quartz, with minor amounts of limonite and disseminated organic material. Like the lower unit, these sandstones are mottled due to bioturbation. These rocks are medium to thick bedded, with horizontal or subhorizontal stratification. At Coal Creek, and farther east, calcareous sandstone concretions are found in the member, usually in the upper sandstones. Concretions increase in numbers as the Panther tongue is traced eastward; they range from a few centimeters to a meter or more in diameter.

Body fossils are not common in the Panther tongue. One bivalve (*Inoceramus*?) was found in the lower 1 m of the tongue at Alkali Creek. Trace fossils are very abundant, however, and most of the identifiable burrows are located in the upper unit. Such trace fossils as *Arthropycus*, *Ophiomorpha*, chevron trails, and annelid worm smooth tubes (Howard 1966a, b, c) are among the most common in the Panther in the quadrangle. Fossils col-

lected by Clark and Spieker have been used to date the Star Point as medial Montanan (Campanian) (Young 1955, p. 182).

Howard (1966a, b, p. 32) concluded that sediments of the Panther Sandstone near Helper, Utah, were deposited in a delta and associated with offshore areas. He considered the basal interbedded siltstone and sandstone to be bottom-set beds and the overlying sandstone as fore-set beds of the delta.

Panther sandstone in Deadman Canyon Quadrangle probably represent a transition zone and lower shoreface environment offshore from a delta. The basal interbedded siltstone and sandstone were deposited in a transition zone between the offshore mudstone environment of the Mancos Shale and the lowermost lower shoreface environment of the delta front sheet sands. Rocks of the upper sandstone were deposited in a lower shoreface environment.

Sediments deposited in the Cretaceous Panther delta were probably transported offshore as suspended load by turbidites and storms. This is supported by the fact that as the tongue is mapped eastward, away from the Panther delta, grain size of the Panther Sandstone decreases. Harms (1975, p. 89) stated that hummocky stratification, found in Upper Cretaceous rocks of the western interior of the United States, represents deposition of sediments under storm wave conditions. Sole marks and hummocky beds suggest the Panther Sandstone sediments were deposited offshore by turbidites and/or storm conditions.

### *Blackhawk Formation*

Young (1955, 1957, 1966, 1976) subdivided the Blackhawk Formation into the Spring Canyon, Aberdeen, Kenilworth, Desert, and Grassy Members. Using this nomenclature, each member contains a basal sandstone unit and associated overlying coal-bearing rocks. Young's nomenclature was modified by Maberry (1971), who subdivided the formation into the Aberdeen, Kenilworth, unnamed lower mudstone, Sunnyside, and unnamed upper mudstone members in the Sunnyside area. The Aberdeen, Kenilworth, and Sunnyside Members consist mainly of cliff-forming sandstones. The lower and upper mudstone members are slope forming, and contain mudstone, siltstone, sandstone, and major coal-producing zones. The Spring Canyon Member is not separately recognizable in the area of Maberry's study, but is in Deadman Canyon Quadrangle (fig. 6).

Maximum thickness of the formation near Castlegate, Utah, is approximately 400 m. The formation is 327 m thick at Coal Creek Canyon in this study area, and it continues to thin eastward from there.

The Blackhawk Formation consists mainly of sandstone, siltstone, mudstone, shale, and coal. As with the

SYSTEM	STAGE	FORMATION	LITHOLOGY	THICKNESS meters (feet)	DESCRIPTION
UPPER CRETACEOUS	CAMPANIAN	Castlegate Sandstone			
		Blackhawk Formation upper mudstone member		55-65 (180-210)	Coastal plain, delta plain, sandstone, mudstone, shale, siltstone, coal, yellow orange, and orange brown
		Sunnyside Member		30-35 (100-110)	Littoral, sandstone, siltstone, yellow orange, gray
		Blackhawk Formation lower mudstone member		R 30-40 (100-150) G K	Delta plain, coastal plain, sandstone, mudstone, shale, coal, pale yellow orange, medium gray
		Blackhawk Formation Kenilworth Member		30-40 (100-150) CB CA	Littoral, delta plain, sandstone, mudstone, shale, coal, pale yellow orange, light gray
		Blackhawk Formation Aberdeen Member		30-75 (100-240)	Littoral, sandstone, siltstone, shale, minor coal, pale yellow orange, medium gray, weak to heavy bioturbation
		Mancos Shale (tongue)		35-40 (110-130)	Offshore marine, siltstone, shale, minor sandstone, medium gray
		Spring Canyon Member		40-46 (130-150)	Littoral, sandstone, siltstone, shale, minor coal, pale yellow orange and medium gray
		Mancos Shale			

FIGURE 6.—Stratigraphic column of the Blackhawk Formation, Alkali Creek, Deadman Canyon Quadrangle. Coal zones are labeled as follows: CA Castlegate A; CB Castlegate B; K Kenilworth; G Gilson; R Rock Canyon, S Lower Sunnyside. (Coal thickness exaggerated.)

Star Point Sandstone, the lower Blackhawk Formation is a series of sandstone tongues that interfinger with the Mancos Shale (fig. 7). Major sandstones are very fine to medium grained, and they coarsen upward. Weathered colors are pale yellowish orange to gray orange, and the upper one to two meters of several of the sandstones are light gray. Rocks are thin to thick bedded, and exhibit bedding structures such as hummocky beds, trough cross-beds, and horizontal stratification. Bioturbation is locally intense throughout the sandstones.

The slope areas between sandstone tongues consist of carbonaceous shale, siltstone, mudstone, and coal, along with thin-bedded lenticular sandstone. These rocks are usually medium grayish brown to medium dark brown and are generally covered. Occasional beds of well-preserved plant fossils and mollusks occur in the slope intervals. The Blackhawk Formation has been dated by Spieker and Reeside (1925, p. 444) as medial Montanan (Campanian), based on plant fossils identified by F. H. Knowlton.

The contact between the Blackhawk Formation and Castlegate Sandstone is an angular unconformity in the Wasatch Plateau (Clark 1928, Spieker 1931, and Young 1955). The upper contact becomes disconformable west of the Wasatch Plateau front, but as one proceeds eastward the contact becomes conformable (Van De Graaff 1969, Osterwald, Maberry, Dunrud 1981). Generally, the precise Blackhawk-Castlegate contact is not widely exposed because the slope-forming upper Blackhawk beds are often buried by Castlegate debris. The contact, where identified, appears to be conformable in the Deadman Canyon Quadrangle. However, an abrupt increase in grain size from the Blackhawk Formation to the Castlegate Sandstone may suggest an unconformity.

Prograding deltas and/or barrier island complexes are considered to represent the environments of deposition of the major cliff-forming sandstone members, whereas terrestrial and transitional environments are represented in the mudstone members. The Blackhawk Formation records the final retreat of the Mancos Sea from central Utah.

Using a combination of subdivisions, recognized by either Maberry or Young, I mapped six members of the Blackhawk Formation. The lowest one is the Spring Canyon Member, succeeded upward by the Aberdeen, Kenilworth, lower mudstone, Sunnyside, and upper mudstone members (fig. 8).

The Spring Canyon, Aberdeen, Kenilworth, and Sunnyside Members consist of one or more sandstone tongues or bars. These littoral sandstone tongues can be subdivided into four distinct lithologic units that represent different depositional environments (fig. 9). All four of these lithologic units may or may not be present in the same sandstone at one time.

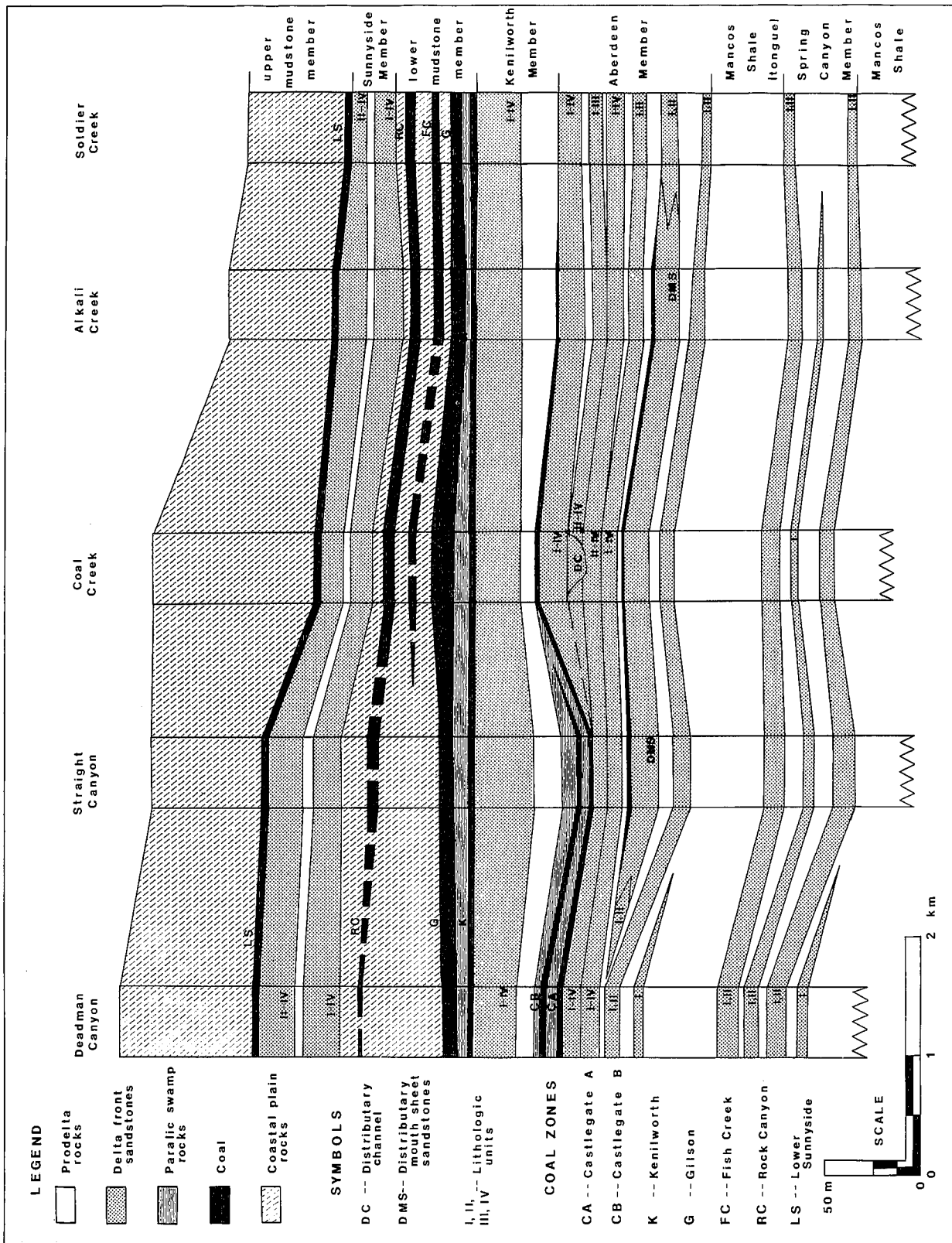


FIGURE 7.—Idealized stratigraphic relationships of the Blackhawk Formation showing paleoenvironments, lithologic units, intertonguing, and major coal zones. (Coal thicknesses exaggerated.)



FIGURE 8.—The Blackhawk Formation, looking to the northwest, at the mouth of Coal Creek Canyon; A Spring Canyon Member; B Aberdeen Member; C Kenilworth Member; D Sunnyside Member.

The lowest unit (lithologic unit I) consists of interbedded siltstones and sandstones (fig. 10). Siltstones weather medium gray, whereas sandstones are pale yellow orange or gray orange. These rocks are generally heavily bioturbated, and both siltstone and sandstone display a mottled appearance. The most common trace fossils are *Ophiomorpha*, *Asterosoma*, and *Helminthoida*. Sandstones are very fine grained, and are composed mostly of quartz, with varying amounts of limonite, lithic fragments, and carbonaceous detritus. Bed thickness ranges from 8 to 30 cm, with thickest beds at the top. Hummocky and horizontal stratification occur along with sharp-crested wave ripple marks, ripple cross lamination, and scattered sole tool marks (Balsley 1982, p. 142). Both upper and lower contacts of the unit are gradational. Rocks of lithologic unit I generally represent transition between lower shoreface and open marine environments (Anderson 1978, p. 69; Balsley 1982, p. 42) (fig. 9).

Lithologic unit II weathers yellowish gray and medium grayish orange. The unit consists of very fine-grained quartz sandstone with limonite, and lithic fragments, in a carbonaceous matrix, and cemented with calcite and minor silica. Beds range in thickness from 30 cm to 2 m in an overall unit that is 12 to 30 m thick. Hummocky and horizontal (flat) stratification are common. Bioturbation is moderate to intense, with some of the dominant trace fossils being *Ophiomorpha* (both horizontal and vertical), *Cylindrichnus*, *Asterosoma*, *Teichichnus*, *Chondrites*, *Thalassinoides*, *Gyrochorte*, *Aulichnites*, *Terebellina*, annelid worm burrows, and helicoidal funnels. These burrows are commonly filled with sediments that have a higher amount of carbonaceous content than surrounding rocks. Lithologic unit II is characteristic of a lower shoreface environment (fig. 9). Sediments in this environment

were affected mainly by bioturbation during calm periods and by storm wave action, represented by hummocky beds.

Lithology III is fine- to medium-grained quartz sandstone that contains minor amounts of disseminated carbonaceous material. Grains are mostly quartz with 2%–5% lithic fragments (black chert) and feldspar (weathered to kaolin). Weathered color is usually gray orange, but can also be very light gray. Bioturbation is locally intense in the unit; *Ophiomorpha*, *Cylindrichnus*, and smooth tube burrows are common trace fossils. Where bioturbation is intense, weathered sandstones can take on a “Swiss cheese” appearance, which is, however, not

LITH. UNIT	LITHOLOGY	STRUCTURES	GRAIN SIZE	BIOTURBATION	ENVIRONMENT
IV			Fine	Weak	Fore-shore
III			Fine to Medium	Weak to Intense	Upper Shore-face
II			Very Fine to Fine	Moderate to Intense	Lower Shore-face
I			Silt to Very Fine	Intense	Transition

KEY			

FIGURE 9.—Four lithologic units of the Blackhawk littoral sandstones in the Spring Canyon, Aberdeen, Kenilworth, and Sunnyside Members of the Deadman Canyon Quadrangle.



FIGURE 10.—Lithologic unit 1 consists of interbedded siltstone and sandstone in several of the littoral sandstones of the Blackhawk Formation in Deadman Canyon Quadrangle.

exclusive to the third unit. Lithology III shows dominant trough cross-bedding with the sets ranging between 0.2 and 0.5 m high. Thickness of the unit ranges from 2 to 7 m.

Distinguishing features of lithology III (fig. 9) are characteristic of high-energy, upper shoreface, deposits in modern environments (Heward 1981, p. 227), and when found in Upper Cretaceous rocks of the western United States have been interpreted as representing an upper shoreface environment (Harms 1975, p. 89; Anderson 1978, p. 76; Balsley 1982). Study of the upper shoreface sandstones (lithology III) in the Blackhawk Formation shows that trough cross-bed axes orientation are either normal or parallel to the strandline (Balsley 1982, p. 106).

Lithology IV consists of fine-grained sandstone that is mostly quartz (96%), with minor black chert, feldspar, and moderate amounts of carbonaceous material. Fresh color is medium dark gray, and weathered color is usually light gray. This unit forms a conspicuous "white cap" on several of the major sandstones, although a white cap is

not characteristic of the upper unit only, for caps may also be seen in the upper few meters of lithology III, in sandstones that do not have this overlying fourth unit. It has been suggested that the white cap is present because of a lack of iron-bearing minerals in the sandstone (Young 1966, p. 13, Anderson 1978, p. 81). The fourth unit commonly is one to two meters thick, and is characterized by horizontal to subhorizontal stratification that dips seaward to 2°–6° degrees (fig. 11). Upper and lower contacts of the unit are sharp. Bioturbation is minimal with only occasional burrows and minor root casts (fig. 12). I found no fossils in rocks of this unit, but Anderson (1978, p. 83) found a bivalve fauna in the Soldier Creek area. The features just described have been interpreted as indicating foreshore or beach environment deposits both in modern and ancient environments (Dickinson and others 1972, p. 195; Harms 1975, p. 89; Reading 1978, p. 147; Balsley 1982, p. 108).

All four lithologic units are not necessarily present in the same sandstone tongue. Sandstones showing an incomplete sequence usually exhibit lithologies I, II, and sometimes III. Occasionally lithology I will be greatly reduced in thickness and consist of only a meter or two of interbedded siltstone and sandstone (Balsley 1982, p. 78). Lithologic units II or III can also be seen directly overlying sandstone of lithology IV in some of the stacked regressive sandstones of the Aberdeen Member.

Orientation of a paleostrandline has been determined by Balsley (1982, p. 61) who measured the orientation of trough cross-bed axes at over 4,500 localities in five different bars of the Blackhawk Formation. A general strandline orientation of northeast to southwest was calculated using the trough cross-bed measurements combined with distributary channel transport direction, gravitational movement of pillow structures, and the fact that flood-plain coals (Gilson seam) tend to pinch out to the south-east.

*Spring Canyon Member.* This member consists of basal sandstone tongues with overlying coal-bearing rocks in the western Book Cliffs (Young 1955, p. 184), but in the Deadman Canyon area the member is composed of four sandstone tongues separated by tongues of Mancos Shale (fig. 7). The sandstone tongues are all similar in lithology, bedding structures, and trace fossils. Rocks of lithologic units I and II constitute the four tongues of the Spring Canyon Member in the quadrangle. All four sandstone bars thin from west to east, and the Mancos Shale interfingered tongues thin from east to west. The second and fourth sandstone tongues were mapped across the quadrangle, but the first and third tongues lose their identity in the Mancos Shale within the quadrangle (fig. 7). The member is predominantly a cliff-forming fine-grained sandstone that grades laterally to a slope-forming sandy siltstone unit.



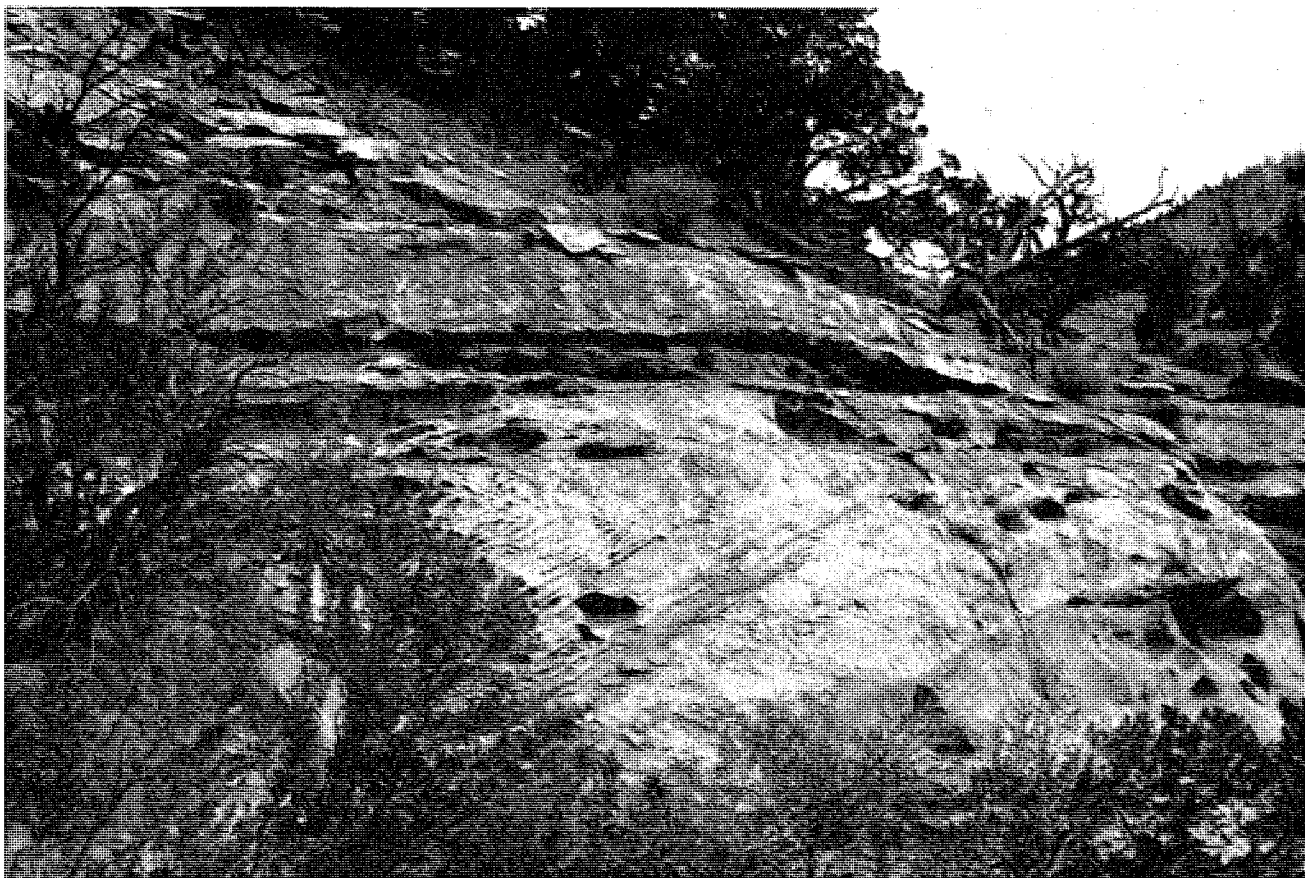


FIGURE 11.—Trough cross-bedded sandstone (lithology III) overlain by horizontally to subhorizontally stratified sandstone (lithology IV) typically found in the Aberdeen, Kenilworth, and Sunnyside Members in Deadman Canyon Quadrangle.

Local maximum thickness of the Spring Canyon Member is about 46 m near Deadman Canyon, and minimum thickness is 40 m near Soldier Creek. The thickest sandstone tongue is 15 m and the thinnest has a maximum thickness of 8 m. Tongues of Mancos Shale occur above and below the Spring Canyon Member. Contacts are gradational at bases of sandstone tongues, and sharp at their tops. Young (1955, p. 184) stated that the upper contact of the Spring Member is slightly disconformable.

Coal is not abundant in the Spring Canyon Member of the Deadman Canyon Quadrangle. However, minor thin and lenticular coal beds are found in the member immediately west of Deadman Canyon.

The Spring Canyon sandstones, like the Panther Sandstone, represent distal margins of wave-dominated shore and nearshore deposits in the Deadman Canyon Quadrangle. Sediments associated with the Spring Canyon tongues in Deadman Canyon were deposited offshore from wave-dominated deltas much like that already described in the Panther Sandstone tongue of the Star Point Sandstone. Sands were carried offshore, away from the delta fronts, by storms, and possibly turbidites. Mudstone and siltstone were deposited during normally calm

periods when deposition was generally slow.

Rocks of lithology II are much thicker and much more developed in the Spring Canyon Member than in the Panther tongue. This suggests that the amount of sediments deposited in the Spring Canyon deltas was greater than the amount of sediments deposited in the Star Point deltas, and probably that the Spring Canyon deltas prograded farther east into the Mancos Sea than the Star Point deltas. Shale or siltstone tongues between the sandstone tongues represent offshore shallow marine deposits like the Mancos Shale, and record transgressions of the Mancos Sea over the regressive Spring Canyon delta fronts.

*Aberdeen Member.* The Aberdeen Member can be mapped across most of the western Book Cliffs from Price River Canyon to Whitmore Canyon (Maberry 1971, p. 22). It consists of one or more sandstone tongues or bars, which are often separated by tongues of Mancos-like siltstone and shale. According to Young (1955, p. 184) the Aberdeen Member, from Kenilworth to Coal Creek Canyon, is composed of five littoral sandstone bars. Each tongue eventually grades laterally into the Mancos Shale. Six major Aberdeen sandstone bars are found in the



FIGURE 12.—Root casts are typical of lithologic unit IV in the littoral sandstones of the Blackhawk Formation.

Deadman Canyon Quadrangle (fig. 7). Sandstones increase from four tongues at Deadman Canyon to six tongues that continue eastward from Coal Creek to Soldier Creek. Sandstone tongues of the Aberdeen Member consist of lithologic units I through IV.

Thicknesses of the Aberdeen Member range from 45 m at Deadman Canyon to nearly 75 m at Alkali Creek. Individual sandstones reach a maximum thickness of 30 m, but average about 18 m.

The Aberdeen Member is underlain by a tongue of Mancos Shale; the contact between the two is gradational. Contacts were mapped where interbedded siltstone and sandstone become most abundant in the lowermost tongue, which coincides with the base of the lowest sandstone cliff. The upper contact of the Aberdeen Member is sharp and was placed at the top of the uppermost sandstone.

The second sandstone tongue from the base of the Aberdeen Member, east of Straight Canyon, consists of seaward dipping accretionary beds (fig. 13). The imbricate pattern formed by the dipping beds is most easily seen in the alternating sandstone and siltstone. Sandstones are fine to medium grained and are made chiefly of quartz with abundant disseminated organic detritus. Much of the organic material was deposited along bedding planes and has a "coffee grounds" appearance. The beds show flat, normally graded, and massive bedding,



FIGURE 13.—Six Aberdeen Sandstone tongues (labeled a–f) 1.5 km east of Coal Creek Canyon. The second sandstone (b) displays seaward-dipping accretionary beds. (Photo taken looking east.)



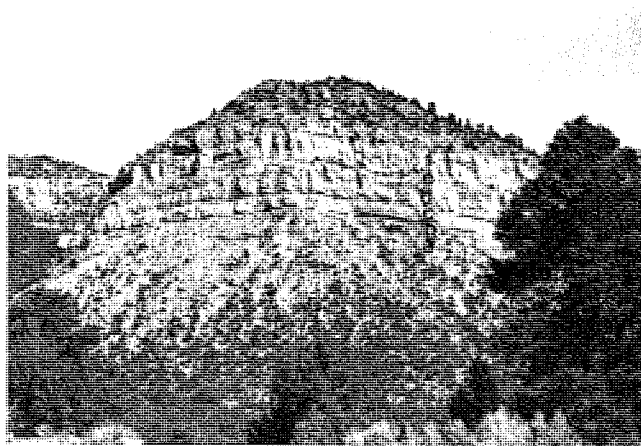


FIGURE 14.—Six Aberdeen littoral sandstones (labeled a–f) incised by distributary channel. Looking northwest, at the mouth of Coal Creek Canyon.

along with parting lineation (Balsley 1982, p. 21). Other bedding structures found include occasional cross-beds, hummocky cross stratification, interference ripple marks, and some directional ripple marks. Soles of beds often have flute and groove casts. Beds are thickest at the top of the sandstone bar, and thin when followed seaward, down section. Bioturbation is moderate to heavy in the upper portions of the beds. Trace fossils identified are *Ophiomorpha*, *Thalassinoides*, and annelid worm smooth tube burrows. Generally this sandstone bar is overlain by a meter of fine-grained marine sediments and thin (0.2 m) coal bed.

The tongue, as just described, can be followed from Straight Canyon to Alkali Creek (fig. 7). Balsley (1982, p. 55) stated that lithologies III and IV are sometimes replaced laterally by these imbricate-bedded “distributary mouth bars” or distributary sheet sands. From Alkali Creek east, the bar probably grades laterally into interbedded siltstone and sandstone.

Six Aberdeen Sandstone bars are seen in the western wall of Coal Creek Canyon (fig. 14). The fifth and fourth sandstones from the base have been incised by a distributary channel that cuts through the fifth sandstone and into the upper lithologic unit of the fourth sandstone. The channel was subsequently filled with sandstone and siltstone.

The six sandstones change somewhat when followed up Coal Creek to the mouth of Hoffman Creek (fig. 15). Six sandstones persist, but the second sandstone exhibits lithologies I and II instead of the imbricate bedding so well defined to the south near the front of the Book Cliffs. Fluvial cross-bedded sandstone is found near the top of the upper sandstone at the Knight Ideal Mine (fig. 16).

Rocks of the Aberdeen Member exhibit upper shoreface, foreshore, distributary channel, and distributary

sheet sand environments, in addition to the offshore, transition, and lower shoreface environments described in the Spring Canyon Member. The upper shoreface environment is represented by rocks of lithologic unit III, and the foreshore environment is represented by rocks of lithology IV.

Distributary sheet sandstones occur also in the Aberdeen Member (fig. 13). These sandstones are seaward dipping and arranged in an imbricate pattern. They do not display transition, lower and upper shoreface, and foreshore deposits, thus being distinguished from the delta front sandstones. Deposition occurred adjacent to distributary channel complexes in the Cretaceous Aberdeen deltas. Distributary sheet sandstone deposits represent high-energy subaqueous flows (turbidites) that originated in river mouths and fanned out probably during times of flood (Balsley 1982, p. 130).

Distributary channels, as seen in sandstones of the Aberdeen Member (fig. 14), were incised into the shoreface sandstones by distributary streams that shifted across ancient delta plains (Balsley 1982, p. 131). The channel recognized at the mouth of Coal Creek Canyon represents a low sinuosity meandering stream that was abandoned and filled with sandstone and siltstone (Balsley 1982, p. 162). Other possible ancient distributary channels associated with the Aberdeen Member (fig. 16) represent active fill of highly sinuous meandering streams on the delta plain.

Barrier bars or wave-dominated deltas have been considered to be the main environments of deposition for the sandstones of the Aberdeen Member and Blackhawk Formation. Young (1955, 1957, 1966, 1973, 1976) stated that the depositional environment of the littoral sandstones in the Blackhawk Formation is predominantly barrier island bars with associated lagoonal deposits. He has also stated that some of the sandstones may have been deposited in deltas. Others (Anderson 1978; Balsley 1982) have stated that Blackhawk Formation littoral sandstones represent predominantly deltaic and associated delta strandline environments, with minor barrier bar deposits.

I agree with Balsley’s conclusions that the Blackhawk littoral sandstones in the Deadman Canyon Quadrangle represent ancient wave-dominated deltas. The presence of distributary channels and distributary sheet sands support the wave-dominated delta idea. Distributary channels and distributary sheet sands similar to those in the Aberdeen Member have been recognized in the Panther Sandstone and have been interpreted as deltaic deposits (Howard 1966a, b, p. 31). Other evidences for wave-dominated deltaic environments in the Blackhawk Formation will be discussed further in this paper.

In general, the Aberdeen Member displays a major regression of the Mancos Sea during Late Cretaceous time. Four to six major deltaic tongues prograded sea-



FIGURE 15.—Six Aberdeen sandstone bars (labeled a–f) overlain by the Kenilworth Member, looking toward the eastern wall of Deadman Canyon at the mouth of Hoffman Creek.

ward over the area now enclosed in the Deadman Canyon Quadrangle. Each regression represented by the sandstones was followed by a minor transgression of the sea over the area. Two other Aberdeen tongues exhibit rocks that were deposited offshore from deltas situated west of the quadrangle. Coals on top of the littoral sandstones show that minor coal swamps developed on the littoral sandstone before the next transgression took place.

**Kenilworth Member.** The Kenilworth Member was named by Young (1955, p. 184) for exposures of the member near Kenilworth, Utah, 3 km west of the Deadman Canyon Quadrangle. He originally defined the member as consisting of a basal thick sandstone and overlying coal-bearing rocks (Young 1955, p. 185). Later, Maberry (1971, p. 23) redefined the Kenilworth Member as consisting of basal interbedded siltstone and sandstone and a massive cliff-forming sandstone, only the lower part of the member as described by Young. I have followed Maberry's usage and have subdivided the Kenilworth Member into a basal siltstone or shale grading upward into a massive cliff-forming sandstone.

The Kenilworth Member is mappable from near Helper, Utah, eastward to the Beckwith Plateau (Ma-

berry 1971, p. 23), and crops out as a nearly vertical cliff with a lower slope-forming unit throughout most of the mapped area. Maximum thickness of the Kenilworth Member is 44 m where measured at Deadman Canyon. The member thins eastward from Deadman Canyon to Coal Creek, but thickens again to the east where it is 42 m thick at the eastern edge of the quadrangle.

Lower contacts of the Kenilworth Member are placed at the top of the uppermost Aberdeen sandstone. This is usually marked by a break from a nearly vertical cliff to a slope. The upper contact is mapped at the top of the Kenilworth sandstone.

The Kenilworth Member is composed of a basal slope-forming unit and an overlying thick sandstone. The lower slope portion changes laterally from siltstone, mudstone, sandstone, and coal at Deadman Canyon to predominantly siltstone east of Coal Creek (fig. 7). Fine-grained clastic rocks are medium grayish brown in the lower portion of the slope, and silty shale is medium gray in the upper and eastern part of the slope in the quadrangle. Coals in the member include the Castlegate "A" and "B" seams. Sandstones are fine to medium grained, contain varying amounts of organic detritus, are thin bedded, and

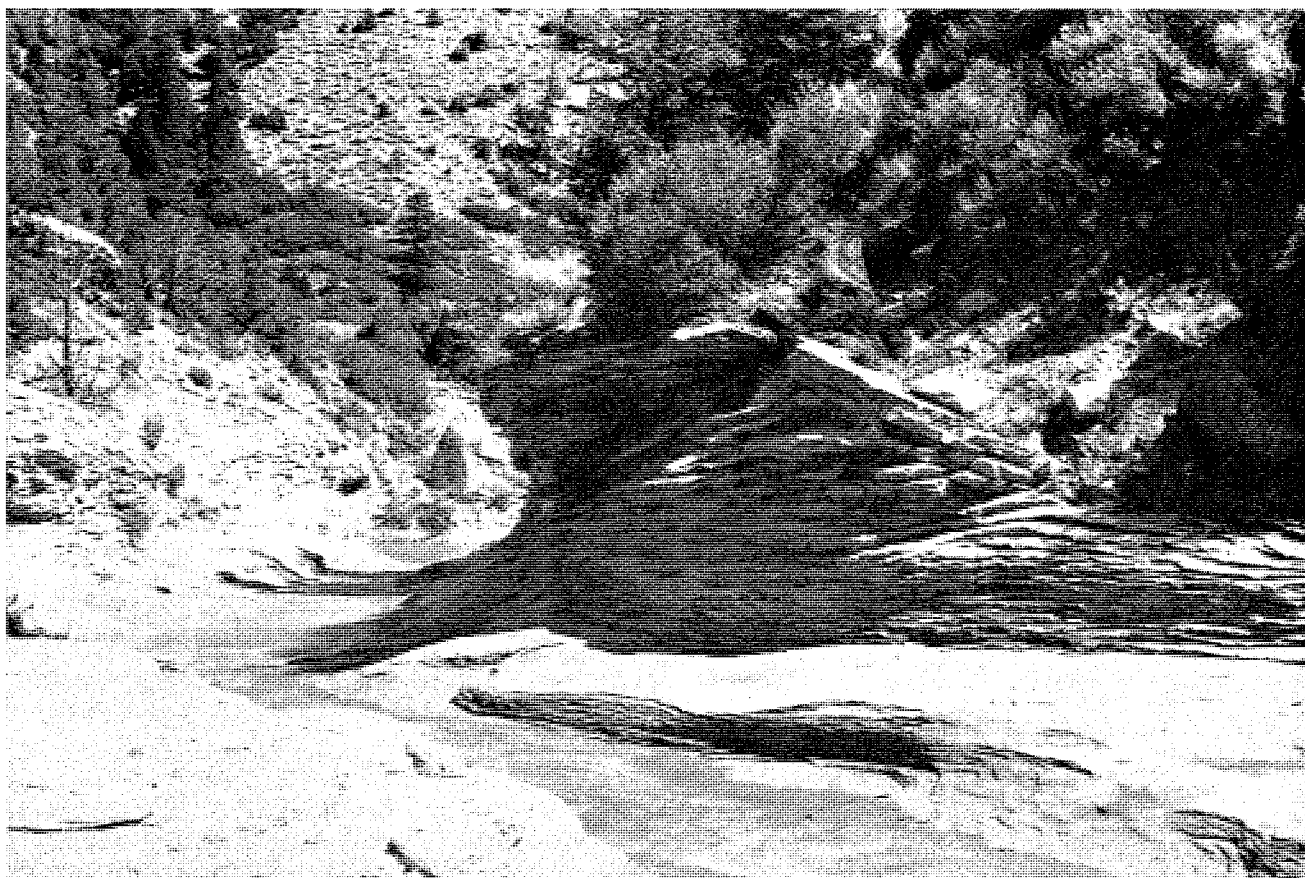


FIGURE 16.—*Fluvial cross-bedded sandstone near the top of the Aberdeen Member 200 m southeast of the old Knight Ideal Mine in Coal Creek Canyon.*

form minor ledges in the lower portion of the slope.

The upper massive sandstone coarsens upward and contains four lithologic units like those previously discussed (fig. 17). This tongue or bar is similar to the uppermost Aberdeen Sandstone with respect to lithology, grain size and composition, bedding structures, color, and trace fossils (fig. 18).

Five general depositional environments are represented in the Kenilworth Member in Deadman Canyon. They are prodelta, delta front and beach sands, delta margin paralic swamps, delta plains, and lower coastal floodplain.

The prodelta environment is similar to that discussed for the Spring Canyon Member. Rocks that accumulated in this environment consist of gray shales and siltstone that generally grade upward to the interbedded siltstone and sandstone of the transition environment. These prodelta rocks usually form a slope at the base of the massive Kenilworth cliff.

Transition, lower and upper shoreface, and foreshore or beach environments are represented by lithologic units I through IV. These environments are displayed in the massive Kenilworth cliff that crops out continuously

across the quadrangle. I believe this sandstone represents shore and nearshore deposits of a wave-dominated delta system, like several of the underlying Aberdeen sandstones.

Delta margin paralic swamps are represented chiefly by fine-grained fossiliferous, brackish water deposits, such as mudstone, siltstone, sandstone, and also minor lenticular coal. These swamps probably formed along the flanks of the Blackhawk deltas in such a way that they were partially protected by isolated sand bars or marginal strandlines, yet they were open to the sea. Salt marshes formed in these brackish water delta-flanking areas, and as a result, narrow lenticular coals were deposited (Balsley 1982, p. 178). Rocks of this environment are found at Deadman Canyon; however, they grade laterally into rocks of the prodelta environment or littoral sandstones before reaching Coal Creek (fig. 7).

The Castlegate "A" and "B" coals were probably deposited in a delta plain environment (Balsley 1982, p. 183). Delta plain coals are often very extensive (20 to 30 miles wide) and reach thicknesses of up to 6 m. Generally coals of the delta plain environment are overlain by sediments of the lower coastal plain fluvial environment or



FIGURE 17.—The massive Kenilworth Sandstone (25 m), as viewed to the southeast at the Knight Ideal Mine in Coal Creek, displays a thick section of lithologic unit II overlain by lithologies III and IV.

paralic swamp sediments in the Deadman Canyon Quadrangle.

Coals of the delta plain environment lie directly on or within a few meters of the top of the foreshore sands of the massive littoral sandstones. This also suggests a deltaic depositional environment for the littoral sandstones instead of barrier island and lagoonal environments. If this were a barrier island lagoonal sequence one would expect to find lagoonal filling deposits on top of the littoral sandstones, followed by coal deposition. Instead, coal is often deposited directly on the sandstone, which suggests coal swamps formed almost directly on the littoral sandstones.

Coastal plain environments are characterized by lenticular and tabular channel-fill sandstones, carbonaceous siltstones, mudstones, and coals in the Deadman Canyon Quadrangle. The sandstones represent meandering stream channel deposits, fine clastics represent overbank flood deposits, and coal was deposited in poorly drained

backswamp areas (Balsley 1982, p. 178).

Generally coals deposited in a coastal plain environment are thin, and very lenticular, but can reach local thicknesses of 2.5 m (Balsley 1982, p. 185). Coals are thinner, less frequent, and are replaced by oxidized overbank deposits the farther away from the paleoshoreline one travels. Rocks of this environment grade laterally into prodelta or littoral rocks before reaching Coal Creek in the lower Kenilworth Member in the Deadman Canyon Quadrangle (fig. 7).

*Lower mudstone member.* The lower mudstone member was originally assigned to the Kenilworth Member by Young (1955, p. 184), but Maberry (1971, p. 23) split the Kenilworth into two distinct parts. The old basal sandstone, as now used, is the Kenilworth Member, and the overlying slope zone is the lower mudstone member. The latter has been mapped as the slope interval between the massive Kenilworth Sandstone and the overlying cliff-forming Sunnyside Member.

Lower contacts of the lower mudstone member are sharp and placed at the top of the Kenilworth Sandstone where there is a break from cliff to slope. Upper contacts are gradational and mapped near the base of the Sunnyside sandstone cliff.

The member was mapped separately at Sunnyside, Utah (Maberry 1971), and can be traced westward toward Helper where it generally forms a slope interrupted by ledges of several thick channel-fill sandstones. This member is most commonly clinkered or oxidized due to burning of underlying coal.

The lower mudstone member consists of mudstone, shale, siltstone, sandstone, and coal. Basal parts of the member contain mostly fine-grained, carbonaceous clastic sediments, mudstone and siltstone, that weather medium grayish brown to medium dark gray.

Main coals of this member are the Kenilworth, Gilson, Fish Creek, and Rock Canyon coal zones in ascending order. The Kenilworth coal seam lies either directly on or within a few meters of the top of the Kenilworth Sandstone. The coal is usually overlain by mudstone and interbedded sandstones. Sandstones are fine to medium grained, weather to a medium pale yellow orange, are usually very thin bedded and lenticular, and contain oscillation and directional current ripples. Sandstone are fine to medium grained, and weather to a medium pale yellow orange.

Several bivalves were found in the lower third of the member above the Kenilworth coal and include *Corbula*, *Ursirvus*, *Anomia*, and *Brachiodontes*. *Crassostrea* occurs in sandy beds (Balsley 1982, p. 172), and a gastropod (probably *Viviparus*) is also found in this zone. Bivalves are brackish water elements and the gastropod is a fresh-water genus, which was probably transported into the area by streams. The zone containing these fossils is

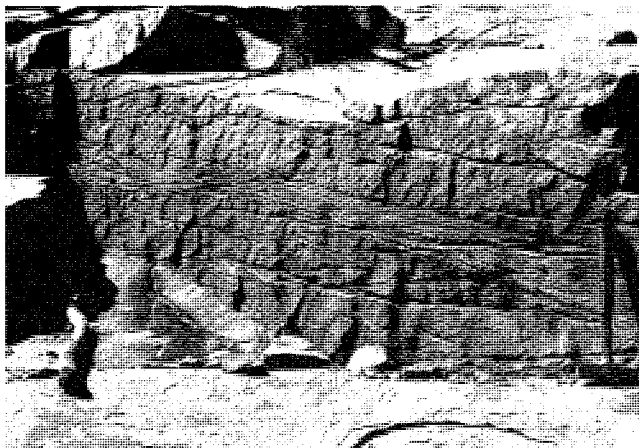


FIGURE 18.—Trace fossil in the lower part of the Kenilworth Sandstone east of the old Knight Ideal Mine in Coal Creek Canyon.

consistently within 2 m of the Kenilworth coal bed. Bioturbation is minimal, with trace fossils being indistinguishable.

The Gilson coal zone lies above these fossiliferous and relatively fine-grained rocks. Siltstone, mudstone, thick sandstones, and many thin- to thick-bedded coal seams occur above the Gilson bed. Mudstone and shale are medium dark gray and carbonaceous. Sandstones weather medium gray orange and are fine to medium grained (fig. 19). The sandstones are thin to medium bedded, lenticular, and exhibit trough cross-beds, directional ripple marks, occasional cut-and-fill structures, and contorted bedding, perhaps produced by soft sediment deformation. Plant fossils, such as *Araucaria* and *Sequoia*, occur in some of the sandstones. Three-toed dinosaur tracks and logs of trees are found in the sandstone that overlies the Gilson seam in the Pinnacle Mine at Deadman Canyon.

Other major coal seams in this part of the member are the Fish Creek and Rock Canyon Coals, along with many laterally discontinuous and uncorrelatable coal seams. Seams are usually highly variable in thickness from one place to the next.

Above the Rock Canyon coal zone is a thin belt of medium gray siltstone that is interbedded with minor sandstone. This belt of rock underlies the cliff-forming Sunnyside Sandstone.

Paralic swamp, delta plain, and coastal plain environments are represented in the lower mudstone member of the Blackhawk Formation in the Deadman Canyon Quadrangle (fig. 7). Coal of the delta plains environment (Kenilworth coal zone) is generally overlain by shale and mudstone of a paralic swamp environment. These rocks are, in turn, overlain by sediments of a coastal plain environment. Coastal plain sandstone, shale, and coal



FIGURE 19.—Channel-fill sandstones and lenticular coals of the lower mudstone member of the Blackhawk Formation at the Knight Ideal Mine in Coal Creek Canyon. (Photo taken looking south.)

occur between the Gilson and Rock Canyon coals in the lower mudstone member of the Deadman Canyon Quadrangle (fig. 19). A thin interval of restricted marine rocks occur above the Rock Canyon coal and below the Sunnyside Member in the quadrangle.

*Sunnyside Member.* Young (1955, p. 185) defined the Sunnyside Member as consisting of a massive basal sandstone and overlying coal-bearing rocks. Maberry (1971, p. 27) redefined the member as including only the basal cliff-forming sandstone of Young's original definition, called the overlying rocks the upper mudstone member. This restricted Sunnyside Member consists of basal interbedded siltstone and sandstone that grade upward to a massive sandstone cliff. I have mapped the Sunnyside Member using Maberry's criteria. The lower contact is gradational and placed at the base of the Sunnyside cliff, and the upper contact was mapped at the top of the massive Sunnyside sandstones.

Anderson (1978, p. 111) concluded that the Sunnyside Member contains two stacked regressive tongues in the Pine Canyon Quadrangle, and that the upper, less continuous, tongue has its westernmost beginning between Coal Creek and Soldier Creek Canyons. However, I was able to map this upper sandstone to Deadman Canyon, and it probably continues westward into the adjoining Helper Quadrangle for some distance (fig. 20). The Sunnyside Member is thickest in the quadrangle near Deadman Canyon, where it reaches a maximum of 19 m, and it thins eastward to about 17 m near Soldier Creek.

Two regressive littoral sandstone bars constitute most of the Sunnyside Member (fig. 7), which show transition, shoreface, and foreshore environments. A thin layer of restricted marine rocks generally occurs between the two regressive sandstones. The Sunnyside Member records deposition of a prograding delta followed by a local minor





FIGURE 20.—Two stacked regressive sandstone tongues of the Sunnyside Member at the Pinnacle Mine in Deadman Canyon as viewed to the northeast.

transgression and then by progradation of another delta sequence.

*Upper mudstone member.* The upper mudstone member was originally part of the Sunnyside Member (Young 1955, p. 185), but Maberry (1971, p. 27) considered the coal-bearing rocks above the Sunnyside Sandstone as a distinct upper mudstone member. Maberry's definition is used in this paper.

The lower contact of the upper mudstone member is sharp and placed at the top of the uppermost Sunnyside Sandstone, but the upper contact with the Castlegate Sandstone is possibly unconformable. This upper contact was generally mapped at the base of the Castlegate cliffs or where coarse-grained, light gray sandstone becomes dominant. Thickness of the upper mudstone member in the quadrangle ranges from 80 m at Alkali Creek to 53 m near Coal Creek.

The upper member is similar, lithologically, to the lower mudstone member, except for an occasional marlstone bed and occurrences of ironstone concretions in the upper member. Mudstone, siltstone, and shale are carbonaceous and weather medium brownish gray. Sandstones are fine grained, mostly quartz, calcareous, usually flat and cross-bedded, weakly bioturbated, and show soft sediment deformation. Most beds are lenticular and thin to thick bedded.

The main coal seam in the member is the lower Sunnyside bed, which lies directly on or within a few meters of the top of the Sunnyside Sandstone. This is the only minable seam in the member in the quadrangle. Other coal seams are too thin and lenticular to be economically exploited. Much of the outcrop belt of this member has been clinkered by burning of the coal.

Rocks of the upper mudstone member were deposited almost exclusively in a coastal plain environment (fig. 7),

but minor paralic swamp and delta plain deposits are also represented in this member in the quadrangle. The Sunnyside coal was probably deposited in a delta plain environment. Rocks of the paralic environment are found above the second Sunnyside littoral sandstone in the upper mudstone member just west of Soldier Creek. Shales, mudstones, and sandstones in the upper mudstone member are very similar to those described for coastal plain deposits in the lower mudstone member, except minor marlstones or calcareous siltstones and ironstone concretions are found in the upper mudstone member. The marlstones are probably associated with lacustrine sediments deposited in the floodplain and the ironstone concretions may have formed as bog iron in backswamps of the floodplain.

### *Castlegate Sandstone*

Where the Castlegate Sandstone is exposed, the formation generally forms a cliff above the Blackhawk Formation. The contact with the overlying Price River Formation is conformable, and has been drawn where the slope-forming interbedded siltstone and sandstone of the lower Price River Formation first appear.

The Castlegate Sandstone is 123 m thick at the type section in Price River Canyon, and thickens to the northwest where it reaches a maximum thickness of 185 m near Bennion Creek (Van De Graaff 1972, p. 569). It is 77 m thick in Deadman Canyon, but no marked thickening or thinning of the formation is noted within the quadrangle.

Predominant lithology is sandstone with minor amounts of interbedded shale and siltstone. Sandstones are medium to coarse grained, and are composed mostly of quartz with varying amounts of clay minerals, chert, and other lithic fragments. Most common types of cement are silica, calcium carbonate, and some minor iron oxide. Lenticular bedding, trough cross-beds, and current ripple marks are very apparent in the Castlegate Sandstone throughout most of the area. In places, the Castlegate Sandstone is very rich in particulate organic material, and wood fragments up to 0.3 m long were found locally. Generally the siltstone and shale beds are very carbonaceous, and sometimes minor lenses of coal occur interbedded in these fine-grained rocks. Spieker and Reeside (1925, p. 446) dated the Castlegate in the Wasatch Plateau as late Montanan.

The Castlegate Sandstone was deposited in a fluvial environment (Van De Graaff, 1972). Most beds appear as braided stream deposits in Wasatch Plateau and western Book Cliffs outcrops. From Deadman Canyon eastward, the sandstone grades from a fluvial sandstone facies until it is in littoral facies near Green River and Thompson, Utah (Grant Willis personal communication 1983).

### *Price River Formation*

In the Deadman Canyon area the Price River Formation has been subdivided into lower and upper unnamed members. The formation crops out in the Book Cliffs and Wasatch Plateau, and in an east-west belt across the northern part of the Deadman Canyon Quadrangle. The lower member is a slope former, and the upper member holds up two to three main ledges that locally form a single massive cliff (fig. 20).

The Price River Formation is 200 m thick at the type section in Price River Canyon, and thins to 125 m in Coal Creek Canyon in the central part of the quadrangle. Thicknesses increase eastward so that near Thompson, Utah, the Price River beds are 650 m (Howard 1966a, p. 15). No marked thinning of the formation was noted in the Deadman Canyon Quadrangle. Regional changes in thickness have been attributed to intertonguing with the Mancos Shale, local warping, and pre-Tertiary erosion (Howard 1966a, p. 15).

Spieker and Reeside (1925, p. 445) defined the upper contact of the Price River Formation as represented locally by a conglomerate of limestone pebbles. Clark (1928, p. 21) stated that the contact between the Price

River and North Horn Formation is unconformable and marked by a basal conglomerate in most places. The contact is gradational and marked by the first appearance of red beds in Price River Canyon (Young 1957, p. 187). Spieker (1946) placed the upper contact of the Price River Formation at a level of greatest lithologic change between the thicker sandstones of the Price River Formation and the variegated mudstone beds of the North Horn Formation. I have used Spieker's (1946) description of the contact for the formation and mapped the top of the Price River beds at the level of greatest lithologic change between lower sandstone and upper fine-grained clastic rocks. This is usually expressed as a break in slope from cliff-forming sandstone up into slope-forming shales. It is difficult to use the first occurrence of red beds as the contact because these red beds are usually covered, except in fresh roadcuts. Several limestone rip-up conglomerates occur in the section, but it is difficult to correlate these beds because of their lenticularity.

The Price River Formation consists principally of sandstone with varying amounts of interbedded siltstone, shale, and mudstone. Lithologically, the formation is similar to the Castlegate Sandstone, but with greater thick-

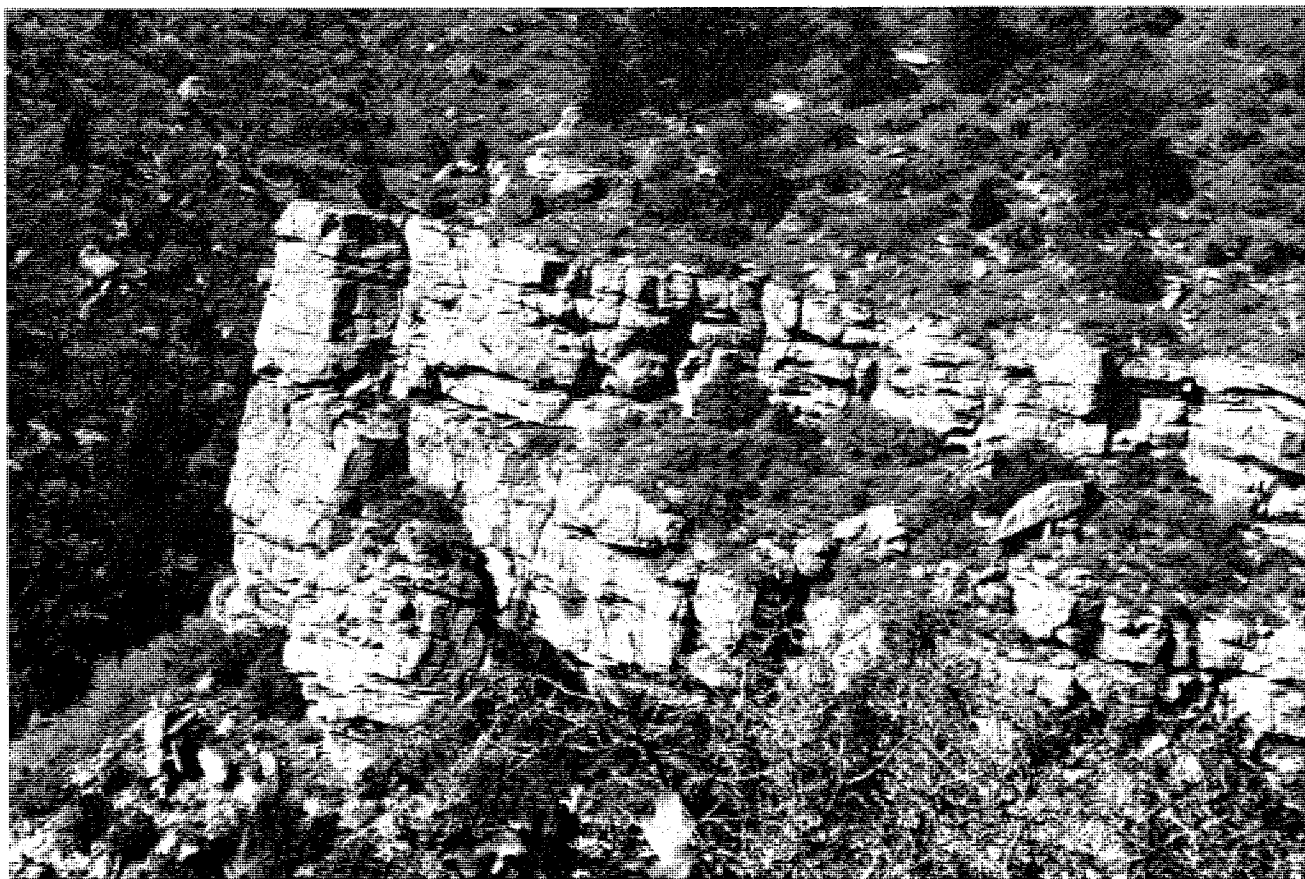


FIGURE 21.—Upper cliff-forming member of the Price River Formation (41 m) looking west in the left fork of Deadman Canyon.



FIGURE 22.—Slope-forming North Horn Formation above the Price River Formation and below the Flagstaff Formation. Looking north up the left fork of Deadman Canyon; A Castlegate Sandstone; B Price River Formation; C North Horn Formation; D Flagstaff Formation.

nesses of fine clastic rocks. This difference in lithology is shown by the cliff-forming Castlegate Sandstone contrasted to the slope-forming lower Price River Formation.

Abbott and Liscomb (1956, p. 122) and Cobban and Reeside (1952) have assigned a Campanian to Maestrichtian age to the Price River Formation. Spieker (1946) stated that the rocks probably change from late Montanan to early Lancean somewhere in the upper Price River Formation.

The Price River Formation represents deposits of fluvial environments in the Deadman Canyon area. Mudstones and other fine-grained clastic rocks were probably deposited on floodplains as overbank deposits during times of flood. Thick sandstones of the formation possibly represent a general braided stream environment, although lenticular sandstones associated with fine-grained rocks are probably channel fills of meandering streams on a floodplain.

*Lower Price River Member.* This member is predominantly mudstone, siltstone, and shale, with interbedded sandstone. Fine clastic rocks are very rich in particulate organic material. Most units are medium gray to medium brownish gray. Mudstones and siltstones are often very thin bedded to laminated. In freshly cut banks, siltstones show directional ripple marks, and paleocurrents associated with these siltstones generally trend toward the east. Interbedded shale contains minor beds of lenticular coal, generally thinner than 0.5 m.

Sandstones are fine to coarse grained, and consist mostly of quartz with varying amounts of feldspar, chert, and other lithic fragments. Many of these sandstone beds are lenticular and are thin to medium bedded. This member exhibits a stair-step alternating ledge and slope exposure. Thickness of the member ranges from 42 m at

Deadman Canyon to 50 m at Clearwater Creek.

*Upper Price River Member.* The upper member consists of sandstone with very minor amounts of shale. Sandstones are coarse to medium grained, displaying an apparent fining upward trend. Colors range from medium gray brown to medium light gray. Sandstones are medium to thick bedded, and contain lenticular beds, cross stratification, and ripple marks (fig. 21).

Shale in this member is carbonaceous, and medium gray. This shale is interbedded with the thick-bedded, cross-stratified sandstone just described. The member is 77 m thick in Coal Creek Canyon.

## CRETACEOUS-TERTIARY SYSTEMS

### *North Horn Formation*

The North Horn Formation weathers to a slope interrupted by ledges of channel-fill sandstones and limestone. It is mainly mudstone and shale, with interbedded thin marlstone, limestone, and sandstone (fig. 22). Minor coal beds occur in the formation in Price River Canyon, but none are exposed in the Deadman Canyon Quadrangle. I have divided the formation into two informal members. The lower member generally has more interbedded sandstone and is coarser grained and less calcareous than the upper member, which has minor interbedded limestone.

At the type section, Spieker (1946, p. 133) measured the formation as 508 m thick. To the east, in Price River Canyon, the formation thickens to 677 m. The North Horn Formation ranges from 337 m thick at Deadman Canyon to 309 m thick just west of Soldier Creek Canyon in the quadrangle.

Fossils were collected from the North Horn Formation in the mapped area, including some freshwater bivalves and gastropods and some fossil leaf fragments. Vertebrate fossils have been collected from the North Horn Formation (Spieker 1946, p. 134). Paul Anderson (personal communication 1983) found a bone of a vertebrate organism (possibly an alligator) in the Pine Canyon Quadrangle. Fossils collected from the formation indicate that it includes Cretaceous and Tertiary rocks, but it is difficult to draw the boundary between the two systems. It generally is agreed, however, that the lower part of the formation is Late Cretaceous and the upper part is early Paleocene.

The contact between the North Horn Formation and overlying Flagstaff Formation is gradational. I have placed the contact immediately below the fossiliferous, relatively clean, blue-gray limestones that appear to be continuous beds.

*Lower North Horn Member.* As already mentioned, rocks in this member are coarser grained and less calcareous than those in the overlying member. The lower unit consists of gray shale and mudstone interbedded





FIGURE 23.—Lenticular channel-fill sandstone (10 m) of the North Horn Formation in Deadman Canyon. (Looking to the northeast.)

with thin beds of grayish orange, medium grained to locally conglomeratic sandstone. The minor sandstones in this argillaceous member contain quartz, lithic fragments, limonite, and weathered feldspar, and appear subarkosic. This part of the member forms a gentle to moderate slope.

More than half of the upper part of the lower member consists of sandstone that weathers medium dark orange brown to gray orange or very light gray, and generally has a salt-and-pepper appearance. Sandstones are medium grained on the average, but range from fine-grained to conglomeratic rocks that contain fine pebble-sized clasts. Sandstones contain quartz, lithic fragments, weathered feldspar, and some clay pebbles or rip-up fragments that give sandstones a conglomerate appearance. The sandstones are thin to thick bedded and contain trough cross-bed sets that are 0.2 to 0.5 m high. These lenticular units are difficult to trace laterally for more than a few tens of meters (fig. 23). They contain wood fragments and disseminated carbonaceous material. The upper sandy half of the lower member usually forms a steep slope or cliff below the slope-forming upper member. The only fossils collected in this member are partial leaf imprints found in

thin-bedded sandstone at Clearwater Creek. Maximum thickness of this member is 149 m near Deadman Canyon, and the member thins eastward to 133 m near Soldier Creek.

The lower member was deposited in floodplain environments (Osterwald and others 1981, p. 23). Fine-grained rocks were probably deposited as overbank flood sediments, and the lenticular sandstone beds represent channel-fill deposits, probably of meandering streams.

*Upper North Horn Member.* The upper member forms a gentle to moderate slope between the sandstones of the lower unit and the resistant cuesta-capping limestones of the Flagstaff Formation. Maximum thickness of the member is 198 m at Clearwater Creek, and minimum thickness is 158 m just west of Soldier Creek Canyon. This member consists of interbedded mudstone and shale, with minor sandstone and limestone. Mudstone and shale in the lower few meters of the member are pale yellowish orange, and those in the upper parts are variegated and red. Argillaceous rocks weather to form a slope. Float on these slopes consists of sandstone, limestone nodules, and a few oncoids. Limestone nodules are medium gray, and at first glance appear like oncoids. When broken open



FIGURE 24.—*Typical basal limestone rip-up conglomerate of channel sandstone in the North Horn Formation in Deadman Canyon (1.5 m Jacobs staff as scale).*

the nodules have no concentric banding, are micritic, and contain some silt.

Sandstones in the upper member are similar to those in the lower member, but are usually more calcareous. Two or three main sandstone ledges consistently have a basal limestone pebble conglomerate (fig. 24). Pebbles in the conglomerates are spherical and are comparable to clay rip-up clasts. Matrix of the conglomerate consists of coarse-grained sand and highly calcareous siltstone. Limestone clasts, which have weathered out, look much like limestone nodules found elsewhere on the shale and mudstone slopes.

Limestone is much more abundant in upper parts of the section. It is usually pale yellowish orange, but one or two beds are dark gray. Sand, silt, and argillaceous material occur in the limestones and make up 15% of the rock. Fossil bivalves and gastropods are found in some limestone lenses. Beds of limestone are less than one meter thick.

The upper member accumulated in mixed lacustrine and fluvial environments. Sandstone and mudstone are similar to those found in the lower unit, but the addition of limestone containing freshwater bivalves and gastropods indicates a greater development of lacustrine environments in the upper part. Thus the environment of deposition is interpreted to have been a low-lying inland floodplain with meandering streams and occasional lakes.

## TERTIARY SYSTEM

### *Flagstaff Formation*

The Flagstaff Formation consists of interbedded limestone, shale, sandstone, and some oil shale at the type locality in the Wasatch Plateau. Gilliland (1951, p. 25, 26) used the term Flagstaff Formation in western exposures instead of Flagstaff Limestone because he found great thicknesses of sandstone and conglomerate in the formation. Others, such as McGookey (1960, p. 596), La Rocque (1960), Runyan (1977, p. 71), and Anderson (1978, p. 45) have also used the term Flagstaff Formation. Ryder and others called the Flagstaff Limestone the Flagstaff Member of the Green River Formation in their study of the Uinta Basin (1976, p. 496, 497). In the Deadman Canyon Quadrangle, the rocks in the Flagstaff interval are different than those described at the type section; therefore, I will call the formation the Flagstaff Formation.

The formation is described as 300 m of limestone that forms high cliffs and parapets at the type area. However, the formation thins considerably to only approximately 80 m in the western part of Deadman Canyon where it crops out as a series of three or four limestone ledges and forms a stripped surface and dip slope between the crest of the Book and the base of the Roan Cliffs. Contacts are gradational between the North Horn and Flagstaff Formations and between the Flagstaff and Colton Formations. The lower contact was mapped at the base of laterally persistent beds of clean, medium gray, fossiliferous limestone, and the upper contact was mapped at the top of the uppermost persistent limestone, where red mudstone and fluvial sandstones become prominent.

Spieker (1949, p. 13) assigned a late Paleocene age to the Flagstaff Formation, and La Rocque (1960) suggested that the formation is Eocene in age. La Rocque later concluded (1960, p. 73) that the lower member is middle and upper Paleocene and the upper member is lower Eocene.

The Flagstaff Formation in the Deadman Canyon Quadrangle consists of interbedded mudstone, shale, limestone, and sandstone (fig. 25). Mudstone and shale are common in the lower and upper parts of the formation. They are usually variegated, red or green, and form



FIGURE 25.—Interbedded shale, limestone (ledges), and sandstone of the Flagstaff Formation (87 m) in Coal Creek Canyon. (Photo taken to the west.)

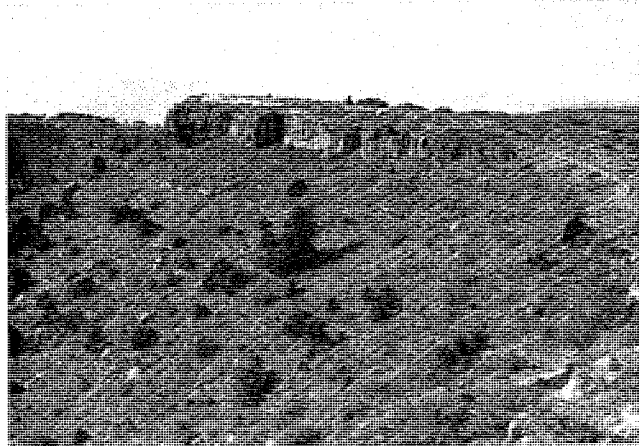


FIGURE 26.—Thick 20 m channel-fill sandstone in the base of the Flagstaff Formation just west of Soldier Creek. (Photo taken looking west.)

slopes. Ledge to cliff-forming sandstone occurs in the slope and ranges from pale olive gray to moderate grayish brown.

Sandstones are medium to coarse grained, show fining upward, and are composed of quartz, abundant lithic fragments, and clay rip-up clasts. Most of the sandstones are medium to thick bedded and are lenticular (fig. 26). Cross-beds and cut-and-fill features are common bedding structures.

Limestones are generally micritic and thin to medium bedded. They weather medium bluish gray to medium dark gray, and hold up ledges. Freshwater bivalves and gastropods are locally abundant in the limestones, here and elsewhere (La Rocque 1960, and Osterwald and others 1981).

The Flagstaff Formation was deposited in a freshwater lake and associated fluvial environments. Ryder and others (1976, p. 499, 500) proposed the term "lake-margin carbonate flat" for a depositional environment that has had extensive nearshore lacustrine carbonate sedimentation and some subaerial exposure. Characteristics of this facies are gray to green calcareous claystone, limestone mud- and grain-supported carbonates, and locally abundant channel-form sandstone beds. These characteristics apply generally to the Flagstaff Formation of the Deadman Canyon Quadrangle.

## QUATERNARY SYSTEM

The Quaternary System is represented by Holocene and Pleistocene deposits in the quadrangle. Generally these are unconsolidated to poorly consolidated, show poor stratification, and vary in grain size from clay-sized particles up to blocks several meters in diameter. Quaternary deposits consist chiefly of alluvium, colluvium, slope wash, pediment gravels, and clinkered zones.

Alluvium is composed of clay to block-sized clasts that have been eroded from bedrock in the area, and deposited in or near stream channels. Such material may be dark brown to dark gray where weathered from Mancos beds or reddish brown where from clinkered or weathered sandstones. The material is unconsolidated to slightly consolidated, and is thin to thick bedded. Cross-bedding may also be present locally. Thickness varies from place to place, but probably is not more than ten meters at any point in the quadrangle.

Colluvium is made up of clay to boulder-sized material that has been transported down slope chiefly by gravity. Such material is pale yellow orange to medium brown in the quadrangle. Clasts are usually poorly sorted and angular to subrounded. Boulders and blocks are massive, attaining diameters of several meters. Colluvium is unconsolidated and covers slopes from the base of the Book Cliffs and partially covers bedrock on the face of the cliffs.

Areas differentiated as slope wash consist of unconsolidated to poorly consolidated clay to sand-sized particles that have been washed into place by running water not confined to specific stream channels (Witkind 1979). In the quadrangle it is generally derived from disintegration of Mancos Shale, and is light to medium gray. These accumulations may be thinly laminated, display crude cross stratification, and generally cover the broad valleys at the base of the gravel-covered Mancos Shale bluffs.

Pediment gravels consist of pebble- to boulder-sized clasts with a matrix of sand and silt. Boulders in some gravel deposits are as large as 2 m in diameter. Clastic debris was derived from the bedrock that makes up the Book Cliffs. These gravels may contain crude channel deposits and a few lenses of clay material. Thicknesses range from 4 to 15 m, with the thickest and coarsest deposits closest to the Book Cliffs. An undulatory ero-



FIGURE 27.—Four pediment levels (labeled a–d) exposed 0.5 km west of the old Young Ranch along Coal Creek road. (Photo taken to the west.)

sional surface under the gravels cuts across Mancos Shale and Panther Sandstone. The terracelike gravel caps rise gently toward the Book Cliff escarpment. They may either slope up to meet the colluvium deposits at the escarpments or they may be truncated (beheaded) before reaching the colluvium-covered escarpment.

Up to five different levels of pediment development and gravel veneer have been mapped in the Deadman Canyon Quadrangle. These different levels are best expressed in the Coal Creek area, near the old Young Ranch (fig. 27). Carter (1977, p. 714) concluded that similar levels cannot be regionally correlated from area to area along the Book Cliffs escarpment because the number of levels is so variable.

Several ideas as to the origin of pediments and the different pediment levels have been suggested. Gilbert (1880) believed that the levels formed due to lateral planation of streams too heavily loaded with sediments to downcut. Rich (1935, p. 1013) believed pediments were formed by sheet wash, and the different levels were formed by dissection of previous pediments due to climatic changes, regrading by escarpment retreat, and possible tectonic uplift. Carter (1977, p. 714) concluded that pediments are produced by valley cutting and widening due to stream erosion, and that the different levels form by stream capture followed by aggradation and subsequent regradation. This seems the most probable model for pediment development in the Deadman Canyon Quadrangle.

Areas that have been burned or clinkered are restricted to the coal-producing members of the Blackhawk Formation (lower and upper mudstone members and lower Kenilworth Member). From a distance the rocks have a characteristic moderate red color. Upon closer inspection the sedimentary rocks appear clinkered and baked. The

burn zone is generally restricted to near the outcrop, but may extend underground up to several hundred feet in from the projected coal outcrops (Michael Glassen personal communication 1982).

## STRUCTURAL GEOLOGY

Structure of the Deadman Canyon Quadrangle is dominated by flank dips northward off of the San Rafael Swell. Strike trends are roughly parallel to the Book Cliffs escarpment, and range from N. 90° W., at Deadman Canyon, to N. 84° W. near Soldier Creek Canyon (fig. 28). Dips range from 4°–7° toward the north, and generally increase slightly from west to east.

Faulting in the quadrangle is minor. No major faults were mapped, and those observed have only a few meters of displacement.

Spieker (1946, p. 156) stated that monoclinial folds of the Colorado Plateau in Utah (including the San Rafael Swell) were formed before deposition of the Flagstaff Formation. Possible thinning of the Price River and North Horn sections in the Deadman Canyon Quadrangle, when compared with adjacent areas to the east and west, suggest that uparching of the San Rafael Swell was contemporaneous with deposition of Price River and North Horn sediments. However, data are insufficient to draw any firm conclusion presently, and detailed analysis of several additional stratigraphic sections outside of this quadrangle will be required to document any pattern.

## ECONOMIC GEOLOGY

Coal is the main economic product of the Deadman Canyon Quadrangle. Building materials and water resources will be required as exploitation of coal and petroleum continues. Several other coal mines have operated in the quadrangle. The Knight Ideal Mine in Coal Creek Canyon was worked for several years before closing in the early 1970s. Several mines have operated in Deadman Canyon in the past, but at present, the Pinnacle Mine is the only operating mine in the quadrangle. Three seams have produced most of the coal taken from the mines in the area; the Castlegate "A," Gilson, and Lower Sunnyside seams. Oil and gas exploratory wells were drilled in the southern half of the quadrangle, near Deadman Canyon and Coal Creek Canyon. Further coal and petroleum development will necessitate upgrading of local roads. An abundant supply of road metal is available in the pediment gravels of the area. Local springs, and intermittent and perennial streams can supply some of the water needed for resource development.

## COAL

Nine coal seams or coal zones have been identified in the Blackhawk Formation of the Deadman Canyon Quad-

range (Clark 1928, p. 36; and AAA Engineering 1979, p. 5), of which only three or four are potentially minable. Coal zones rather than individual seams were mapped because of the lenticularity of the seams; however, I will use the terms "zone" and "seam" interchangeably. Main coal-producing zones in the quadrangle occur in the lower part of the Kenilworth Member and in the lower and upper mudstone members of the Blackhawk Formation. Present minable coal seams include the Castlegate "A," Gilson, and Lower Sunnyside zones, and nonminable coal zones are the Castlegate "B," Royal Blue, Kenilworth, Fish Creek, Rock Canyon, and Upper Sunnyside zones. Many other thin, lenticular, and unnamed coal seams are present in the quadrangle. Coal zones I mapped include the Castlegate "A," Castlegate "B," Kenilworth, Gilson, Rock Canyon, and Lower Sunnyside beds. At present the Gilson and Lower Sunnyside zones are being mined, and plans are underway to mine the Castlegate "A" seam in Deadman Canyon (Michael

Glassen personal communication 1983). Thinner seams are not, at present, economical to mine; however, they may be economically mined or may be targets for in situ coal gasification projects in the future.

Samples (Doelling and Graham 1972) from the Gilson seam at Knight Ideal Mine were analyzed for moisture, volatile matter, fixed carbon, ash, sulfur, and BTU per pound. Statistics for these factors were averaged for the 137 samples taken, and the coal is classified as high-volatile bituminous B rank, based on these averages (American Society for Testing and Materials 1977).

Total coal reserve tonnage (in short ton) has been estimated at 4,700,000 tons for five minable coal seams (AAA Engineering 1979, p. 10). The coal zones included in this estimate are the Castlegate "B," Lower Sunnyside, Gilson, Kenilworth, and Castlegate "A" beds, in order of decreasing tonnage. Guidelines followed for tonnage estimation were set by the U.S. Bureau of Mines and U.S. Geological Survey (1976).

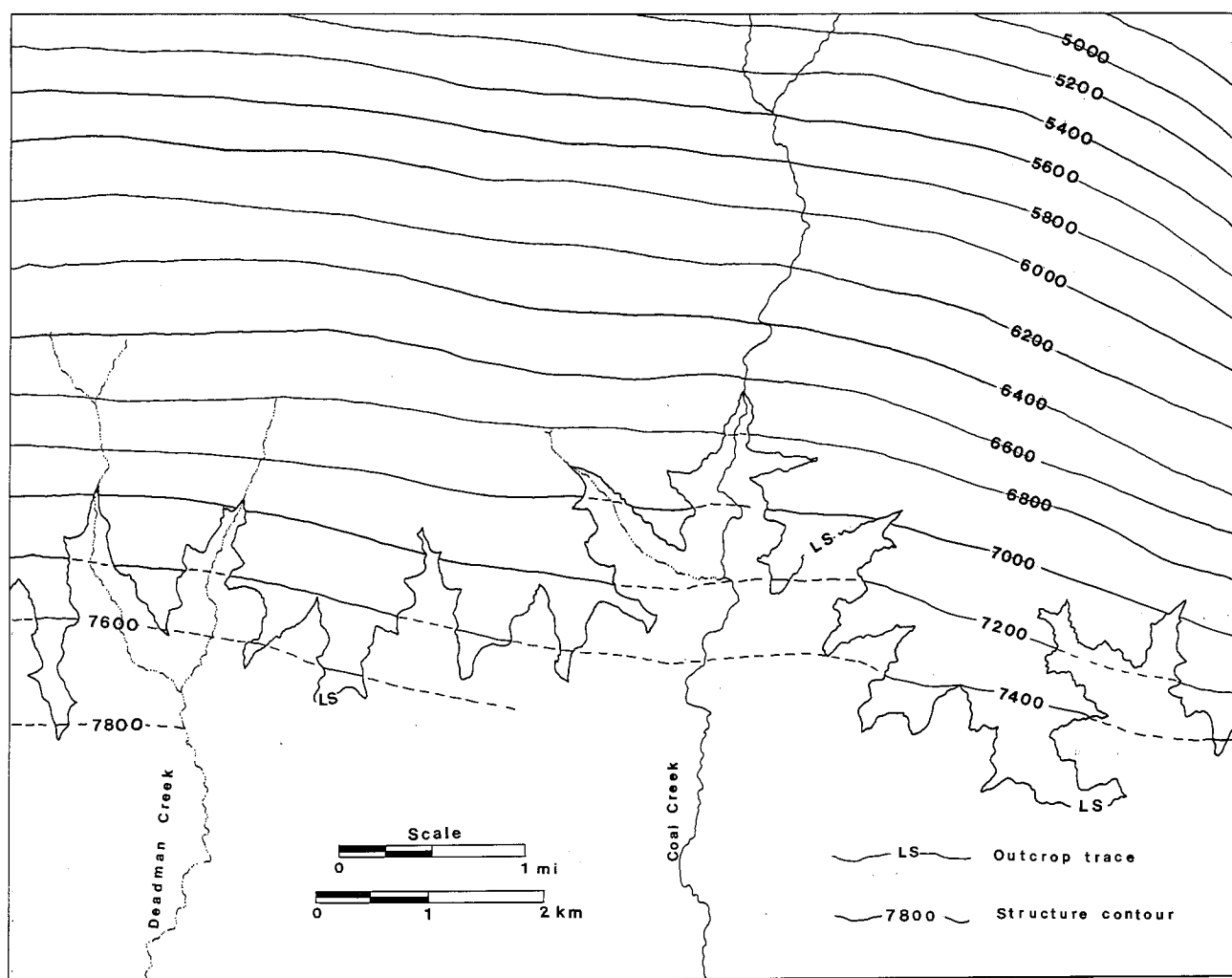


FIGURE 28.—Structural contour map of the Deadman Canyon Quadrangle on top of the Lower Sunnyside coal.

Coal development in the future in the quadrangle will remain principally that of subsurface mining, and possibly in situ coal gasification. Surface mining can probably be ruled out in the quadrangle because of the rugged topography, and the high amount of overburden. Potential is good for subsurface development of coal in the quadrangle. All areas of unleased federal coal land in the quadrangle have high development potentials (AAA Engineering 1979, p. 11). This means that coal beds are at least 1.5 m thick and covered with no more than 300 m of overburden in a given area. Data for determining coal gasification potential are incomplete at present, so no estimates are available. Because of the number of coal seams in the quadrangle, however, coal gasification will undoubtedly be considered in the future.

### Castlegate "A" Coal Zone

The Castlegate "A" coal zone lies above the Aberdeen Member in the basal slope-forming zone of the Kenil-

worth Member. The Castlegate "A" seam can be mapped from the Deadman Canyon Quadrangle westward about 20 miles (Clark 1928, p. 30).

Most of the thickness information comes from outcrop measurements, for subsurface data are limited (fig. 29). Generally the coal zone is thickest in the west and north and thin in the eastern part of the quadrangle. The coal is lensing and reaches a maximum thickness of .8 m (5.8 ft) just west of Straight Canyon. From Straight Canyon eastward, the coal generally thins until it pinches out near Alkali Creek. Average thickness of the coal zone is 1.1 m (3.5 ft).

Burning of this zone at and near the surface is restricted to the western part of the quadrangle. The interval between this coal zone and the overlying Castlegate "B" coal zone is 2 to 10 m (7 to 35 ft). Data from measured sections indicate that the floor rock for the seam is sandstone and carbonaceous shale, and the roof rock is sandstone, siltstone, and carbonaceous shale.

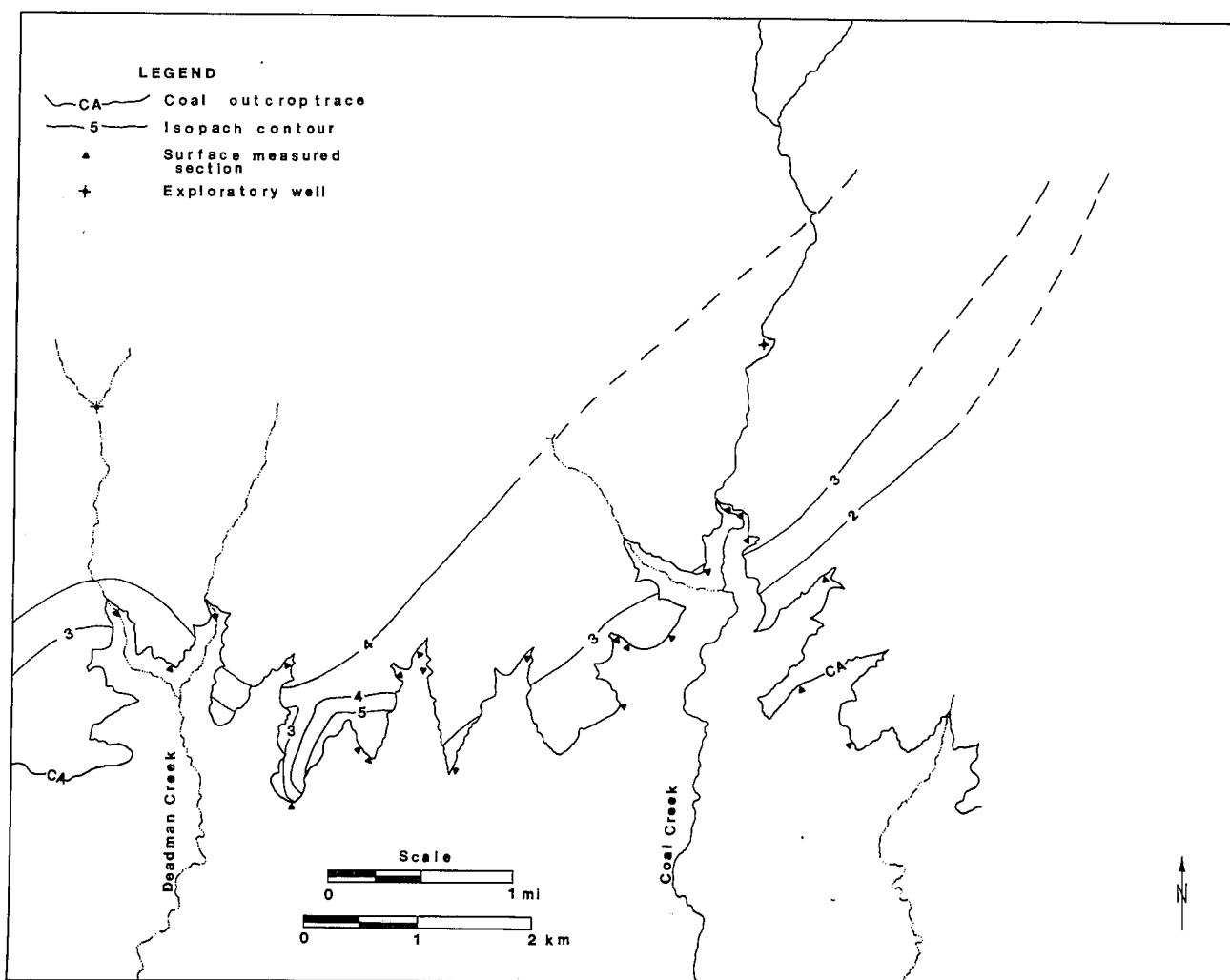


FIGURE 29.—Isopach map of the Castlegate "A" coal zone in the Deadman Canyon Quadrangle. (Contour interval 1 ft.)

### Castlegate "B" and Royal Blue Coal Zones

These coals are located between the Castlegate "A" and Kenilworth coal zones. The seams have been mined in the Helper Quadrangle to the west, and are restricted to the western half of the Deadman Canyon Quadrangle.

Both coals are thin and lenticular, and only the Castlegate "B" coal zone reaches minable thicknesses in the quadrangle. Average thickness of the Royal Blue zone is 0.3 (1 ft), and average thickness of the Castlegate "B" bed is 0.8 m (2.5 ft) (fig. 30). Maximum thickness of the

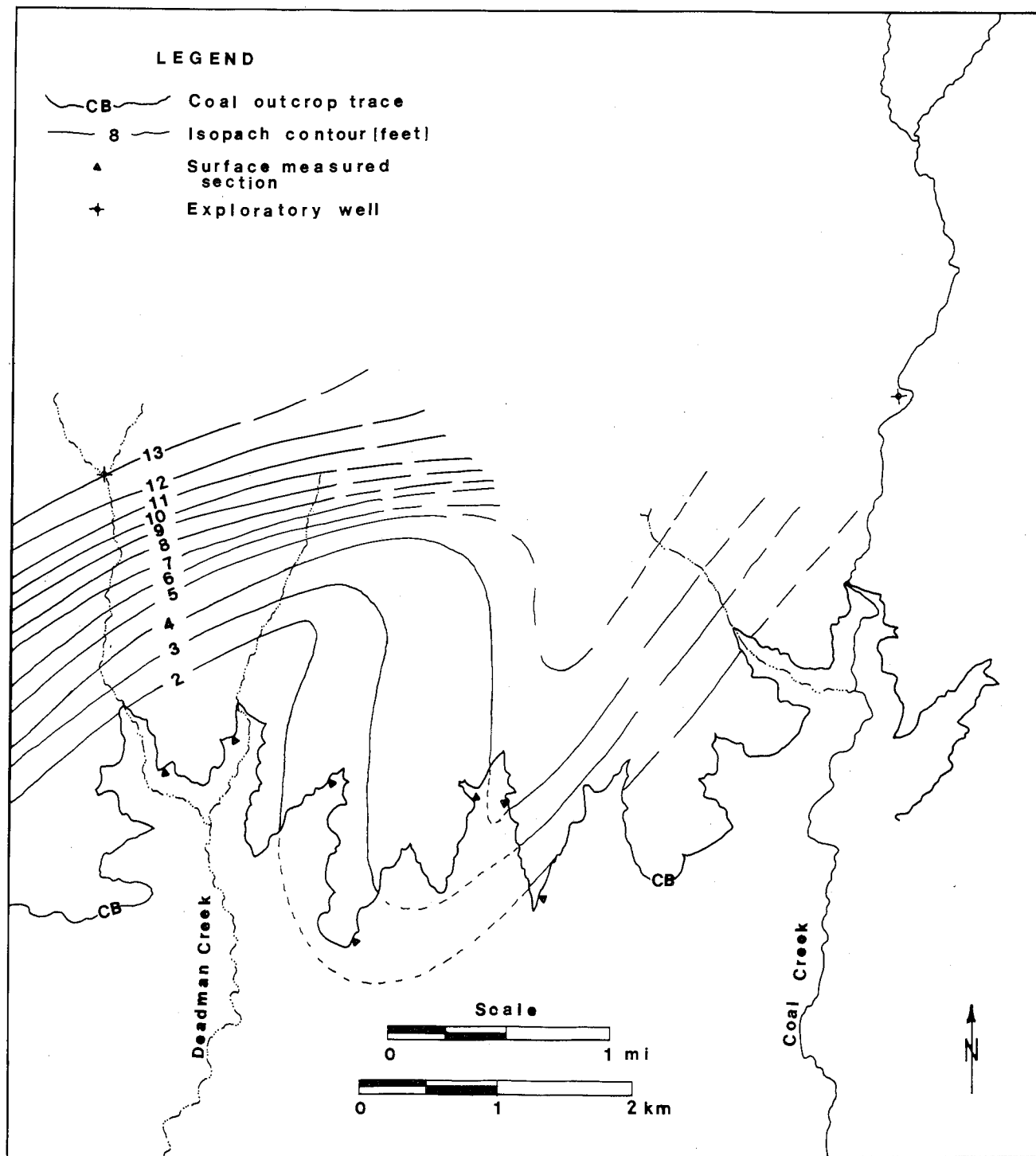


FIGURE 30.—Isopach map of the Castlegate "B" coal zone in the Deadman Canyon Quadrangle. (Contour interval 1 ft.)

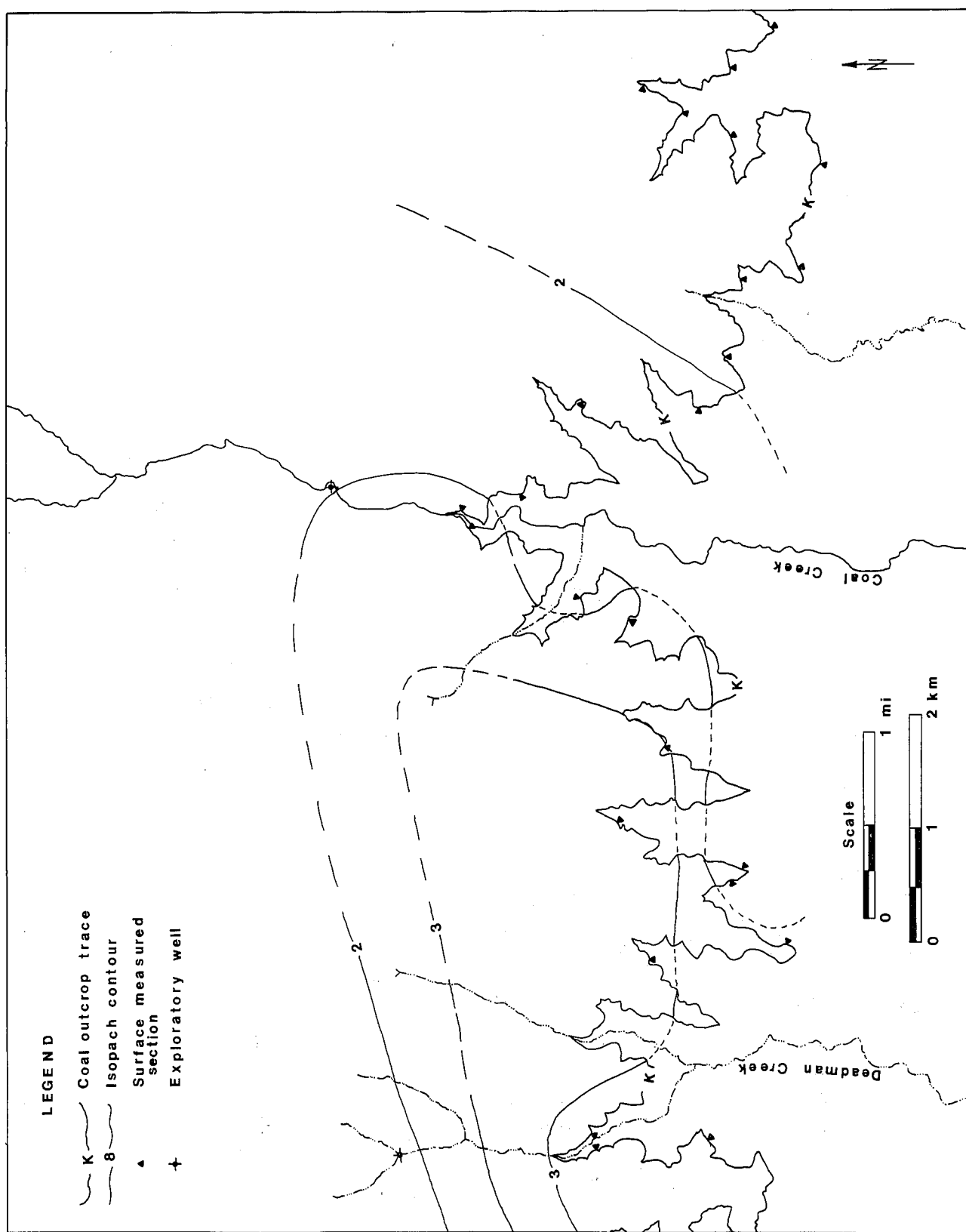


FIGURE 31.—Isopach map of the Kenilworth coal zone in the Deadman Canyon Quadrangle. (Contour interval 1 ft.)



Castlegate "B" is 4.0 m (13 ft) in a drill hole in the left fork of Deadman Canyon (fig. 30). Roof rock is mainly sandstone and siltstone, and floor rock is siltstone and carbonaceous shale. The Castlegate "B" coal zone may possibly be developed in the future, but more extensive data are required to determine its reserves in the quadrangle.

### *Kenilworth Coal Zone*

This zone lies consistently within a meter or two of the top of the Kenilworth Sandstone. The zone crops out nearly continuously across the Deadman Canyon Quadrangle and has been mapped for 33 miles along the western Book Cliffs and northern Wasatch Plateau (Clark 1928, p. 39). It is mined at Kenilworth, where it is 6 m (19 ft) thick. Coal of the zone has variable thickness due to the lenticularity of the bed, and is not found in some measured sections because of erosion of the Kenilworth coal swamp by Cretaceous streams, possibly due to nondeposition of the coal.

Average thickness of the seam is 0.7 m (2.3 ft) with a minimum measured thickness of 0.3 m (1 ft) and a maximum thickness of 1 m (3.5 ft). Generally the zone appears to be thickest west of Coal Creek and thins to the east (fig. 31). Thickness of the interval between the Castlegate "A" and Kenilworth coal zone is between 55 and 75 m (160 and 250 ft). Roof rock and floor rocks are mostly carbonaceous shale and sandstone. The Kenilworth coal should be considered for possible future development, even though mining of this zone is not presently economical in the quadrangle.

### *Gilson Coal Zone*

Clark (1928) suggested that the Gilson coal is a split from the Kenilworth coal in the Helper Quadrangle. The Gilson zone extends from the Helper Quadrangle eastward across Deadman and Pine Canyon Quadrangles. This seam is considered the most important coal zone in the quadrangle (Doelling and Graham 1972) and has been mined extensively in Coal Creek and Deadman Canyons (fig. 32).

Gilson coal is highly lenticular and variable in thickness within the quadrangle. Coal thickness ranges from 3 m (9 ft) at Coal Creek to under 1 m (3 ft) at several locations (fig. 33). The bed is approximately 2 m (6.5 ft) thick in the Deadman Canyon area, and thickens to 2.3 m (7.5 ft) to the east. The seam is thinner at outcrops in the southernmost escarpments of the Book Cliffs (1.3 m) and tends to thin considerably in the subsurface to the north (Michael Glassen personal communication 1982). A drill hole in the left fork of Deadman Canyon (fig. 33) indicates that the Gilson seam thins to only 0.5 m (1.7 ft). Measured surface coal sections display seam thickness of 2.3 m (7.5 ft) at Straight Canyon that thins to 1.2 m (4 ft) in Hoffman

Creek. Outcrop and subsurface mine measurements, in part from Doelling and Graham (1972), show that the Gilson coal zone thickens again to a maximum of 3.4 m (11.1 ft) at Coal Creek. Drill holes in Coal Creek Canyon (fig. 33) document thinning of the Gilson zone to the north (1.5 m). Subsurface data are lacking east of Coal Creek, but measurements of outcrops suggest that the coal thickness averages approximately 1 m (3.3 ft) there.

Splits are a main concern in the Gilson coal. Boney splits and steep pitches of the coal beds make mining difficult and expensive in the Coal Creek area (Doelling and Graham 1972). One main split, averaging 0.2 m thick, is recognized in the Deadman and Straight Canyon areas. Interburden thickness between the Gilson coal zone and the overlying Fish Creek coal zone ranges from 8 to 18 m (25 to 65 ft).

Roof and floor rocks consist predominantly of sandstone and carbonaceous siltstone. Roof competency is very good in the Pinnacle Mine at Deadman Canyon. However, problems occur where the mine workings cross under a ravine or other surface drainage. The main roof problem is the occurrence of "kettle bells" (Michael Glassen personal communication 1982). Kettle bells are diagenetic, cone-shaped, and slickenside features that fall from the roofs of coal mines in the Book Cliffs (Young 1976, p. 12). Continued development of this coal zone is promising in the future.

### *Fish Creek and Rock Canyon Coal Zones*

These coal zones are very thin and lenticular in the Deadman Canyon Quadrangle. The belt of rock containing these two coal zones is usually extensively burned; therefore, mapping and measuring the zones was difficult.

Clark (1928) traced the Fish Creek Coal from Fish Creek, east of the Deadman Canyon Quadrangle, to just west of Soldier Creek Canyon, and stated that the coal possibly extends farther west to Coal Creek. Coal in the Fish Creek zone is thin, no more than 1 m thick, and usually contains several splits.

The Rock Canyon coal zone has been mapped from Rock Canyon, several km east of the Deadman Canyon Quadrangle, to just west of Coal Creek Canyon (Clark 1928). Coal in the Rock Canyon zone is thicker than the Fish Creek coal. Maximum thickness of the former coal is nearly 1.5 m at Straight Canyon, and averages 0.9 m (2.9 ft) between Coal Creek and Deadman Canyon (fig. 34). The coal thins between Coal Creek and Soldier Creek, but thickens again at Soldier Creek, where it is presently being mined by Soldier Creek Coal Company.

Generally roof and floor rocks consist of siltstone and minor sandstone for the Rock Canyon zone. The Fish Creek coal zone is usually 5 to 15 m (15 to 45 ft) above the



FIGURE 32.—*Gilson seam at the Knight Ideal Mine in Coal Creek Canyon (Jacob's staff for scale), as viewed to the southeast.*

Gilson coal zone, and the Rock Canyon coal zone is 5 to 15 m (15 to 45 ft) above the Fish Creek coal zone. Subsurface and outcrop coal thicknesses generally are not available, but limited data indicate that the Rock Canyon coal zone has some potential for future development. The Fish Creek coal does not appear to hold much promise within the quadrangle.

#### *Lower and Upper Sunnyside Coal Zones*

The Lower Sunnyside coal zone has been mapped from Sunnyside, Utah, across the Deadman Canyon Quadrangle and into the Helper Quadrangle (Clark 1928). Coal in the Upper Sunnyside zone in the Deadman Canyon Quadrangle is correlated to the upper coal seam mined at Sunnyside, Utah. It is very lenticular, and has not been mapped nor extensively measured in the quadrangle. The Lower Sunnyside coal, however, has been mapped across the quadrangle mainly because of its position above the Sunnyside Sandstone.

The Lower Sunnyside coal is presently mined in Deadman Canyon, where it reaches a maximum thickness of about 1.5 m (5 ft). Outcrop measurements show that the Lower Sunnyside bed thins eastward from Coal Creek, and develops several major splits (fig. 35). Drill data

indicate that the coal thickens to over 2 m in the left fork of Deadman Canyon, and is a little over 1 m thick in the subsurface at Coal Creek.

Interburden between the Kenilworth and Lower Sunnyside zones is between 60 and 80 m (190 and 250 ft). Floor rock is composed mainly of sandstone and carbonaceous shale, and roof rock is chiefly siltstone and shale with minor sandstones. Potential for development of the Lower Sunnyside coal zone seems good; however, as with several of the other coal zones, more subsurface information is needed to get a better idea of the zone's economic potential.

#### OIL AND NATURAL GAS

Several wells have been drilled in the southern half of the quadrangle in search for oil and natural gas. The main target was the Ferron and Emery Sandstones. One well drilled near Deadman Canyon in 1956 had a show of gas; however, subsequent drilling in that area (Price no. 3 well, NE  $\frac{1}{4}$ , NW  $\frac{1}{4}$ , section 19, T. 13 S, R. 11 E and Price no. 5 well, NW  $\frac{1}{4}$ , SW  $\frac{1}{4}$ , section 20, T. 13 S, R. 11 E) yielded only dry holes. Two additional exploratory wells were also drilled in the Mancos Shale near Coal Creek (Coal Creek no. 1, SE  $\frac{1}{4}$ , SE  $\frac{1}{4}$ , section 18, T. 13 S, R.

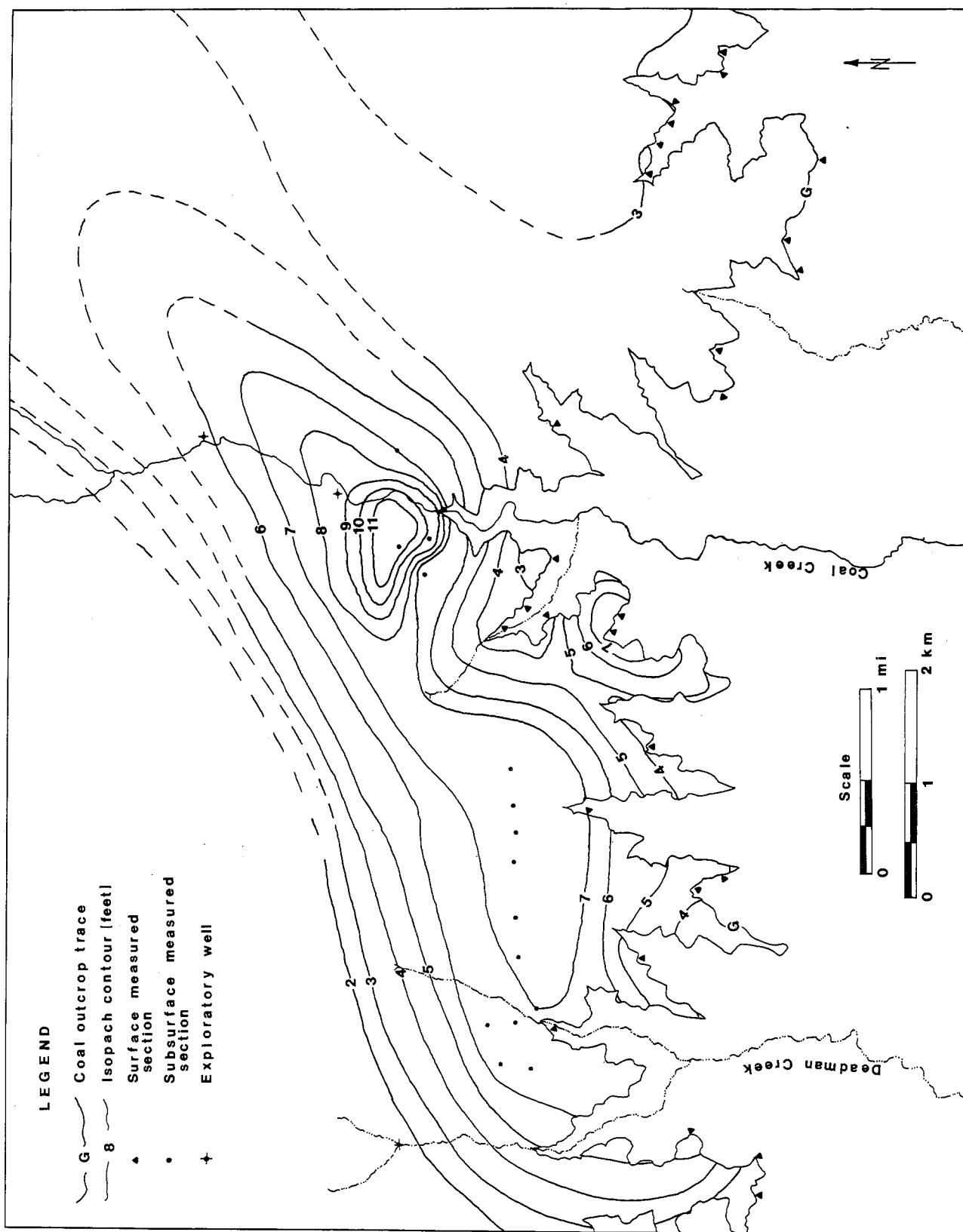


FIGURE 33.—Isopach map of the Gilson coal zone in the Deadman Canyon Quadrangle. (Contour interval 1 ft.)

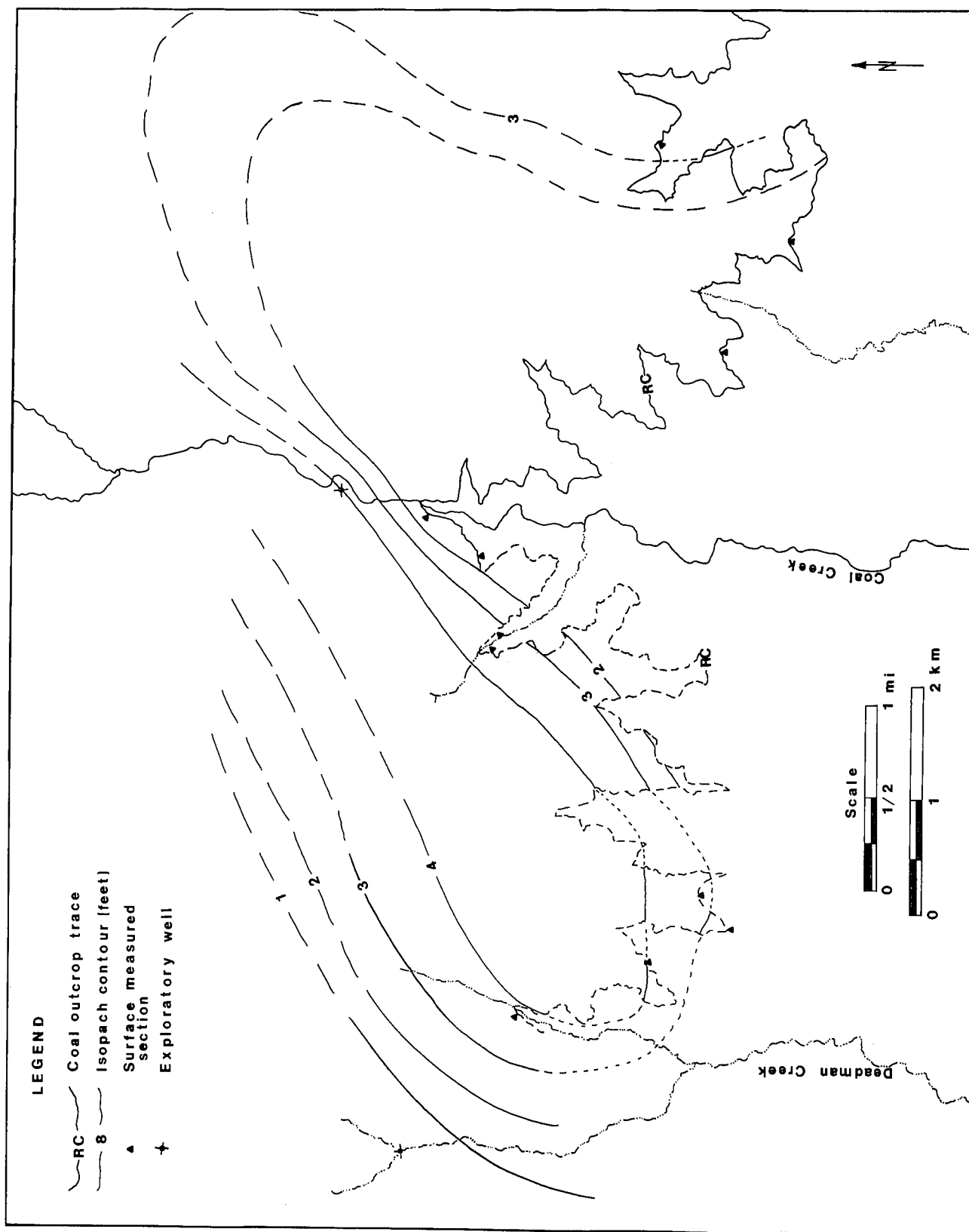


FIGURE 34.—Isopach map of the Rock Canyon coal zone in the Deadman Canyon Quadrangle. (Contour interval 1 ft.)

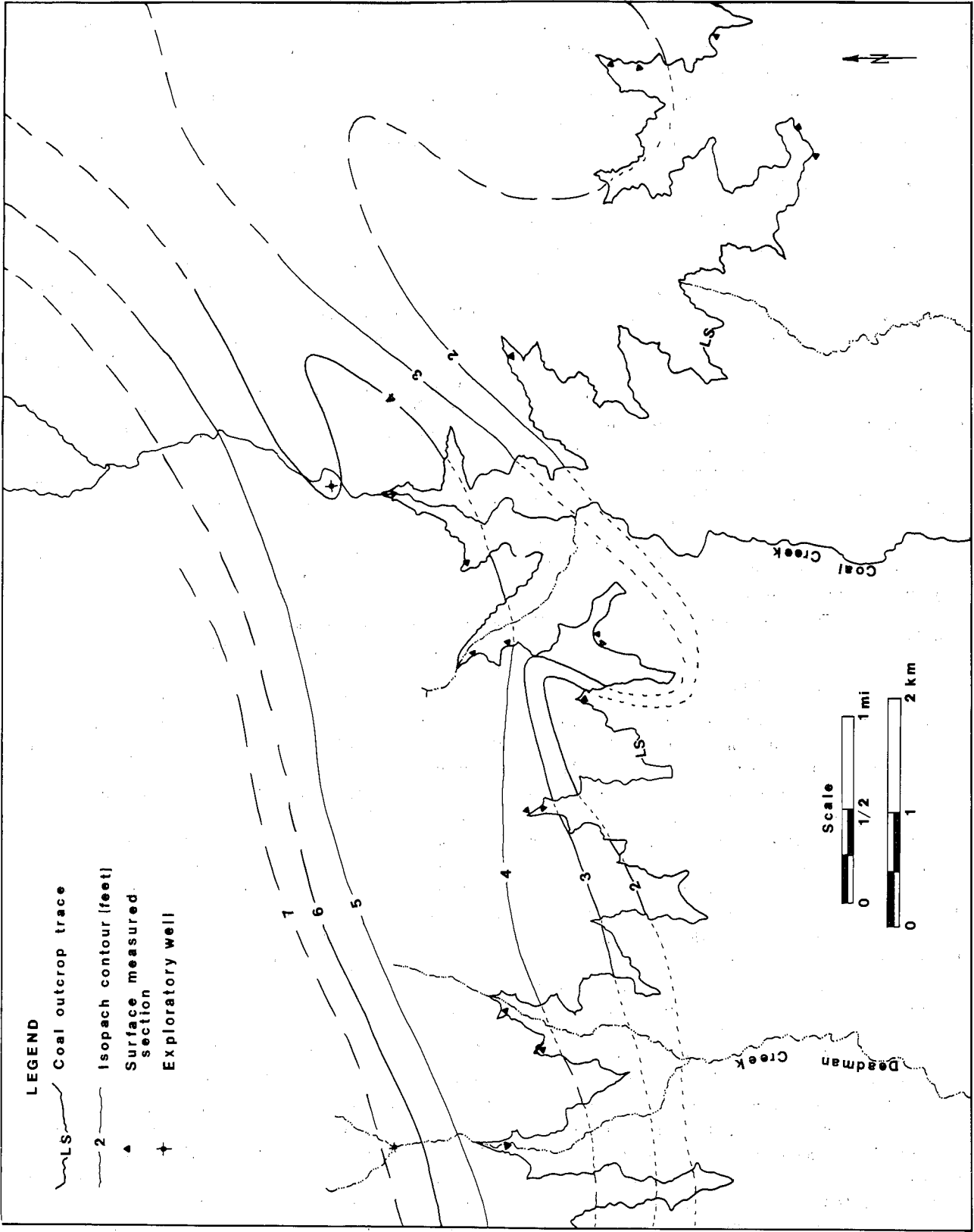


FIGURE 35.—Isopach map of the Lower Sunnyside coal zone in the Deadman Canyon Quadrangle. (Contour interval 1 ft.)

11 E, and Coal Creek no. 2, SW 1/4, SW 1/4, section 10, T. 13 S, R. 11 E), but neither of these wells produced.

Homoclinal dips and unfaulted sections have made no known petroleum traps in the quadrangle. However, interfingering of the sandstones in the lower Blackhawk and marine shales of the upper Mancos Shale could create stratigraphic traps for petroleum in areas to the north. Further exploration should be considered there.

## BUILDING MATERIALS

Unconsolidated gravel provides abundant material for road construction in the area. Several gravel pits have been developed in the pediment gravels along Utah 53 (SW 1/4, NW 1/4, section 1, T. 14 S, R. 11 E). Other smaller gravel pits also have been opened along the roads leading to Coal Creek and Deadman Canyons.

## WATER RESOURCES

One perennial stream and many intermittent streams occur in the Deadman Canyon Quadrangle. Coal Creek and several of its tributaries have flowing water all year. However, in late summer, the flow of the streams is minimal (except for flash floods). Intermittent streams as a rule flow only during the spring and early summer. Many springs are also active in the spring and early summer, but most dry up by the end of August. The Coal Creek Canyon area has the greatest amount of water available for year-round use.

## SUMMARY

Mancos Shale accumulated in a Late Cretaceous shallow seaway that covered much of east central Utah. Star Point Sandstone and tongues of the Spring Canyon Member of the Blackhawk Formation represent distal margins of wave-dominated deltas that prograded eastward into the Mancos Sea. These sandstone tongues mark the beginning of regression of the Cretaceous sea from the Deadman Canyon area. Four to six stacked regressive littoral sandstones of the Aberdeen Member represent wave-dominated deltas, strandline deposits, and associated distributary channels and distributary sheet sands. Coal above the Aberdeen Member was deposited in delta plain swamps. Brackish water shale, siltstone, and sandstone overlie these delta plain coals.

A minor transgression of the sea was then followed by deposition of the Kenilworth Sandstone that also represents progradation of a Cretaceous wave-dominated delta. The Kenilworth coal (delta plain environment) lies above the Kenilworth Sandstone, which in turn is overlain by fossiliferous mudstones, shales, siltstones, minor sandstone, and coals of a paralic swamp environment.

The Gilson coal zone lies above rocks deposited in a paralic swamp, and generally marks the beginning of

sediments deposited in stream channels, backswamps, and lakes of a fluvial coastal plain environment. These conditions existed until a shale-producing marine transgression occurred again in the Deadman Canyon Quadrangle. Two stacked wave-dominated delta littoral sandstones of the Sunnyside Member mark the final retreat of the sea from the Deadman Canyon area. These regressive sandstones are overlain by coastal plain coals and sandstone and mudstones of the upper mudstone member of the Blackhawk Formation.

The Castlegate Sandstone and Price River Formation represent predominantly fluvial deposits. These deposits have a western source—probably the Sevier orogenic belt. The Cretaceous-Tertiary North Horn Formation and the Tertiary Flagstaff Formation represent deposition in fluvial-lacustrine and lacustrine environments respectively. Uplift of the San Rafael Swell possibly caused thinning of Price River and North Horn beds in the quadrangle. However, data are insufficient to be certain.

A thin veneer of Quaternary gravel and alluvium blankets pediments cut across much of the Mancos Shale exposure belt at the base of the Book Cliffs. These deposits are debris eroded from the retreat of the Book Cliffs escarpment.

Three coal seams have been or are presently being mined in the quadrangle, including the Gilson, Lower Sunnyside, and Castlegate "A" coal zones. Future exploitation potential is good for these seams, as well as for the Castlegate "B" and possibly the Kenilworth and Rock Canyon coal zones.

The Gilson seam averages 1.5 m (4.4 ft) thick across the entire quadrangle, but west of Coal Creek average thickness of this seam is 1.9 m (6 ft). The Castlegate "A" (1.1 m, 3.3 ft) and the Castlegate "B" (0.8 m, 2.5 ft) coal zones are also thicker in the western half of the quadrangle. The Kenilworth coal seam averages 0.7 m (2.0 ft) thick across the quadrangle. Coal in the Rock Canyon zone averages 0.9 m (2.8 ft) from sections measured east of Straight Canyon. Further subsurface data are required to determine reserves of the thinner coal zones.

## APPENDIX

### MEASURED SECTIONS

#### *Flagstaff and North Horn Formations*

The section was measured near the head of the left fork of Deadman Canyon. Starting point was at the top of the Price River Formation cliff in the bottom of the canyon (SE 1/4, SE 1/4, section 1, T. 13 S, R. 11 E). The section was measured up the slope to the top of the cuesta-capping Flagstaff Formation that forms a dip slope north of the Book Cliffs escarpment (NE 1/4, SE 1/4, section 1, T. 13 S, R. 11 E).

Unit	Description	Unit Thickness (meters)	Cumulative Thickness (meters)			
20	Mudstone, sandstone, limestone; mudstone, weathers medium gray and variegated, mostly covered slope; sandstone, medium gray, weathers gray brown, medium grained, minor cross stratification, lense-shaped channel-fill sandstone, medium to thick bedded; limestone, medium gray, weathers medium light gray, fossil fragments, mostly bivalves, forms slope with ledges.	45.5	45.5			
19	Covered interval and limestone, slope is probably shale or siltstone, weathers medium gray; limestone, micritic, medium gray, weathers same, fossil fragments, bivalves and gastropods, forms slope with minor limestone ledges.	10.5	56.0	14	18.5	129.2
18	Sandstone, limestone; sandstone same as unit 1; sandy limestone, upper 1.5 m, fossiliferous micritic limestone, gastropod and bivalves, medium gray, weathers medium blue gray, forms ledge.	3.0	59.0	13	6.0	135.2
17	Siltstone, limestone; siltstone is covered, soil weathers medium orange brown; limestone, medium blue gray, weathers medium brownish gray, sandy, very well indurated, gastropods and bivalves, 1 m thick ledge, forms slope and limestone ledges.	10.3	69.3	12	53.5	188.7

Base of the Flagstaff Formation and top of the North Horn Formation

	Total thickness of the Flagstaff Formation		69.3
16	Shale or siltstone, sandstone, and limestone; mostly covered interval, limestone and sandstone float; sandstone, weathers pale yellow orange, very fine grained; limestone float increases upward and contains bivalve fragments; limestone, weathers medium brownish gray, silty, argillaceous, forms slope with minor sandstone and limestone ledges.	96.2	96.2
15	Sandstone, reddish brown in the lower part of the unit, medium pale yellow orange near the top, basal conglomerate, coarse to fine grained, fines upward, clasts are calcareous, probable rip-up clasts, 8 mm to 1.3 cm in diameter, organic detrital material and coarse-grained sandstone lie on top of this conglomerate, angular grains,	14.5	110.7

Base of upper member of the North Horn Formation and top of the lower member of the North Horn Formation

	Thickness of the upper member of the North Horn Formation		188.7
11	Covered slope, soil weathers medium brownish gray, probably siltstone and mudstone, 1 m of limestone rip-up conglomerate at top of the unit, forms slope.	5.0	5.0
10	Sandstone, medium light brown gray, weathers medium brown gray, very coarse grained to conglomeratic, fines upward to fine-grained sandstone, less than 1% black chert, 1%–2% weathered feldspar, cross-bedded, black chert helps cross-beds to show up, limonitic staining, cross sets from 1.5 m to 0.2 m high, most are 0.2 to 0.5 m high, abundant wood fragments in outcrop up to 0.6 m long, possible current direction—N. 90° E., lensing beds—prob-	16.5	21.5

	bly channels, soft sediment deformation, forms cliff to ledge.		
9	Covered interval, probably the same as unit three, forms slope.	8.5	30.0
8	Sandstone, medium orange brown, weathers medium orange brown, medium grained, interbedded with fine-grained sandstone, cross-bedded, mostly quartz, 1%-2% weathered feldspar, possible current direction S. 70° E., medium to thick bedded, laminar cross-beds near the top (upper meter), forms cliff to ledges.	8.5	38.5
7	Covered interval, medium gray soil, probably same as unit three, forms slope.	15.5	54.0
6	Sandstone, medium orange gray, weathers medium dark orange brownish gray, medium grained to very coarse grained, lower 3 m are medium-grained sandstone, 5% limonite, 1%-2% weathered feldspar kaolin, cross-bedded, medium to thick bedded, upper three meters is medium-grained sandstone with lenses of coarse to very coarse sandstone, some thin beds are almost conglomeratic, with clay rip-up pebbles, about 8 mm in diameter, friable, cliff to ledge former.	6.5	60.5
5	Covered interval, probably the same as unit three, forms slope.	6.5	67.0
4	Sandstone, has salt-and-pepper look, very light gray (almost white), weathers light gray, medium to fine grained, dark grains are probably black chert, also some weathered feldspar, fine grained has some black chert, but not as much as medium-grained sandstone, due to limonitic staining some cross-beds are very obvious, medium to thick bedded, friable, in fine-grained sandstone some ripple marks that show current direction N. 120° E. possible, possible channel lenses in fine-grained sandstone, ledge to cliff former.	5.0	72.0
3	Covered interval, probably shale, and siltstone with minor sandstone, small pieces of medium-grained sandstone appear as float, slope former.	66.0	138.0
2	Sandstone, medium orange gray, 142.50.5 weathers medium dark brownish gray, medium grained, abundant limonite, dark gray chert 1%, 5% kaolin from weathered feldspar, poor outcrop, very friable, very thick bedded, possi-	4.5	

	ble cross-beds, forms ledge to slope.		
1	Covered interval, probably shale or silty shale slope former.	6.0	148.5

Base of the lower member of the North Horn Formation and top of the upper member of the Price River Formation

Total thickness of the lower member of the North Horn Formation 148.5

### *Price River Formation and Castlegate Sandstone*

This section was measured in the left fork of Deadman Canyon starting at the top of the Blackhawk Formation. The outcrop is located at the base of the massive Castlegate sandstone cliff at the junction of the first major canyon to the right in the left fork (NE 1/4, NE 1/4, section 12, T. 13 S, R. 10 E).

Base of the lower member of the North Horn Formation and top of the upper member of the Price River Formation

6	Sandstone, minor shale, medium light gray, weathers same, medium to coarse grained, lenticular bedded, looks like Castlegate sandstone, first sandstone cliff 16.5 m thick, shale forms steep slope, shale interbedded with sandstone, sandstones in this slope are about 1 to 1.5 m thick, slope is 12.0 m thick, upper cliff is 12.5 m thick, same as lower sandstone in this unit, forms ledge to cliff.	41.0	41.0
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Base of the upper member of the Price River Formation and top of the lower member of the Price River Formation

	Thickness of the upper member of the Price River Formation		41.0
5	Shale, minor coal, sandstone; shale, carbonaceous, medium gray, forms covered slope; at 1.5 m is coal, 0.1 m thick; at 3.0 m is sandstone, medium gray, weathers medium grayish brown, forms slope and ledge.	14.0	14.0
4	Sandstone and shale; weathers medium pale yellow orange; sandstone, medium grained, 90% quartz, 5% lithic fragments, minor feldspar and chert, medium bedded, forms ledge and cliff.	9.0	23.0
3	Sandstone and shale; sandstone weathers medium light pale yellow; shale weathers medium dark gray, at 5.0 m is abundant hematite staining and minor concretions; at 9 m is 1.5 m bed of car-	19.0	42.0



bonaceous shale, shale is more abundant in lower half of the unit and sandstone is dominant in upper half of the unit, forms slope.

Base of the Price River Formation, top of the Castlegate Sandstone

	Total thickness of the lower member of the Price River Formation		42.0
2	Sandstone, very light gray, weathers medium light gray, medium to coarse grained, predominantly quartz, silica, and calcite cemented, lenticular bedding, at 1.5 m are ripple marks, possible current direction of N. 80° E., abundant cross-beds at 6 m, forms cliff.	57.0	57.0
1	Sandstone, very light gray, weathers light gray, 95% quartz, 1% black chert, 4% weathered feldspar-kaolin, lenticular bedded, some cross-beds, abundant wood fragments in upper meter of the unit, forms ledges and very steep slope.	20.0	77.0

Base of the Castlegate Sandstone, top of the Blackhawk Formation

	Total thickness of the Castlegate Sandstone		77.0
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*Blackhawk Formation (Aberdeen Through Upper Mudstone Members)*

This section was measured at the old Sutton Mine area up an eastern tributary to Deadman Canyon (SE ¼, NE ¼, section 18, T. 13 S, R. 11 E). The section was started at the base of the lowest Aberdeen Sandstone tongue and was continued to the base of the Castlegate Sandstone. Top of the upper mudstone member of the Blackhawk Formation and base of the Castlegate Sandstone

23	Covered and burned interval, some ironstone concretions near top of unit, several minor sandstone ledges; sandstone, weathers gray orange, medium to fine grained, cross-beds, possible cut-and-fill structures, one minor calcareous siltstone bed near the top of the member, probably coal shale, siltstone, and mudstone under cover, forms slope with minor sandstone ledges.	71.0	71.0
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Base of the upper mudstone member and top of the Sunnyside Member

	Thickness of the upper member of the Blackhawk Formation		71.0
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22	Sandstone, weathers medium gray brown, light gray and light red, partially oxidized, fine to medium grained, coarsens upward, intense to weak bioturbation, hummocky cross-beds in lower 10 m, trough cross-beds in next 6 m, upper 2 m are horizontally stratified, wood fragments, forms cliff.	19.0	19.0
21	Covered interval, probably siltstone and sandstone, weathers gray and medium orange brown.	2.0	21.0

Base of Sunnyside Member and top of the lower mudstone member

	Thickness of the Sunnyside Member of the Blackhawk Formation		21.0
20	Siltstone, sandstone, coal; siltstone, weathers medium brownish gray, laminated, carbonaceous; sandstone, weathers medium brownish gray, fine grained, cross-bedded, soft sediment deformation, lenticular shaped beds; coal seam at 1 m, .1 m thick, forms slope with minor sandstone ledges.	14.8	14.8
19	Sandstone, weathers medium orange brown, medium to fine grained, minor clay pebble conglomerate near top of bed, thin bedded, cross-bedded, lenticular beds, forms cliff.	3.3	18.1
18	Shale, sandstone; shale, medium gray, weathers gray orange, thin bedded, carbonaceous, silty; sandstone, weathers medium orange brown, very fine grained, carbonaceous, very thin bedded, forms slope.	2.0	20.1
17	Coal, mostly covered, weathers very dark gray, roof and floor rock is carbonaceous shale, Rock Canyon coal.	1.4	21.5
16	Same as unit 13.	2.6	24.1
15	Sandstone and shale; sandstone, orange weathers same, fine grained, 3% limonite and weathered feldspar, cross-bedded, lenticular beds; shale, carbonaceous, weathers medium brownish gray, forms cliffs with minor shale recess.	7.5	31.6
14	Siltstone, weathers medium gray, thin bedded, minor carbonaceous material, minor very fine-grained sandstone lentils.	13.5	45.1
13	Coal, black weathers black, roof and floor rock are siltstone, Gilson coal.	1.4	45.1

12	Siltstone, same as unit 9, seam, shale, and siltstone are carbonaceous.	1.6	48.1	1	Coal, weathers black, sandstone below and carbonaceous shale above, forms covered slope.	1.5	43.5
11	Sandstone, shale; sandstone weathers pale yellow orange, very fine grained, disseminated organic material, directional ripple marks, cross-bedded, soft sediment deformation, lenticular beds; shale, weathers medium gray, carbonaceous, laminated, minor ironstone concretions, forms cliff with minor shale recesses.	5.7	53.8				
10	Coal, black weathers black, silty, roof and floor rock are carbonaceous shale, forms covered slope.	0.54	54.3				
9	Shale, weathers very dark gray, thin bedded, carbonaceous, forms slope.	1.1	55.4				
8	Siltstone, sandstone; siltstone, weathers medium brownish gray; sandstone, weathers medium gray orange, fine grained, very thin bedded, lenticular, bivalve zone at 3.2 m, forms slope.	11.5	66.9				
7	Coal, black weathers black, forms covered slope, Kenilworth coal.	0.4	67.3				
6	Shale, weathers medium gray, very thin bedded, forms covered slope, carbonaceous.	2.7	70.0				

#### Base of the lower mudstone member and top of the Kenilworth Member

	Thickness of the lower mudstone member of the Blackhawk Formation		70.0				
5	Sandstone, medium gray brown, weathers medium orange brown, becomes light gray in upper 3.0 m, fine to medium grained, coarsens upward, weak to intense bioturbation that decrease upward, hummocky beds in lower 15 m, trough cross-beds dominant in middle 6 m, laminar horizontal beds in uppermost 1 m, medium to thick bedded, forms cliff.	22.5	22.5	2	Covered interval probably shale; similar to unit 4, weathers medium gray, forms steep slope.	5.0	44.6
				1	Sandstone, siltstone, same as unit 3 of this member.	3.0	47.6
4	Siltstone, shale, sandstone; mostly covered interval, siltstone and shale, weathers medium gray, carbonaceous, laminated; sandstone, weathers medium gray orange, very fine to medium grained, lenticular, very thin bedded, interbedded with siltstone and shale, forms slope.	4.5	27.0				
3	Coal, weathers very dark gray, carbonaceous shale below and thin sandstone and carbonaceous shale above, Castlegate "B" coal.	1.5	28.5				
2	Same as unit 4.	13.5	42.0				

#### Base of the Kenilworth Member and top of the Aberdeen Member

	Thickness of the Kenilworth Member		43.5				
6	Sandstone, medium gray brown, weathers medium orange brown and light gray in uppermost 3.0 m, fine to medium grained, coarsens upward, 2% black chert, 2% limonite, 1% weathered feldspar, weak to intense bioturbation that decreases upward, burrows— <i>Ophiomorpha</i> , vertical annelid worm smooth tubes, "Swiss cheese" appearance, medium to thick bedded, hummocky and horizontal bedding, trough cross-beds, uppermost 1 m is horizontally bedded, forms cliff.	15.3	15.3				
				5	Same as unit 6 of this member.	17.8	33.1
				4	Covered interval, probably shale, weathers medium gray brown, forms steep slope.	2.0	35.1
				3	Interbedded siltstone and sandstone; sandstone weathers medium pale yellow orange, fine grained, abundant organic detritus, intensely bioturbated, hummocky and horizontal beds; siltstone, weathers medium brownish gray, intensely bioturbated, forms cliff with siltstone-forming recesses.	4.5	39.6
				2	Covered interval probably shale; similar to unit 4, weathers medium gray, forms steep slope.	5.0	44.6
				1	Sandstone, siltstone, same as unit 3 of this member.	3.0	47.6

#### Base of the Aberdeen Member top of Mancos Shale (tongue)

	Thickness of the Aberdeen Member of the Blackhawk Formation		47.6				
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#### Blackhawk Formation (Spring Canyon Member), Star Point Sandstone, Mancos Shale (Tongues)

This section was measured 1 km east of Deadman Canyon road near the mouth of Deadman Canyon. The section was started at the base of the Panther Sandstone tongue and measured up slope to the base of the first Aberdeen Sandstone (SW 1/4, SE 1/4, section 18, T. 13 S, R. 11 E).

Base of the Aberdeen Member, top of Mancos Shale tongue

8	Covered slope, probably siltstone, weathers medium brownish gray, forms steep slope.	40.0	40.0
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top of unit is a sandstone ledge .5 m thick, very fine-grained sandstone, covered interval forms slope.

#### Base of the Mancos Shale tongue and top of the Spring Canyon Member of the Blackhawk Formation

	Total thickness of the Mancos Shale tongue		40.0
7	Sandstone and interbedded siltstone, sandstone, weathers pale yellowish orange, very fine grained, intensely bioturbated, hummocky and horizontal stratification, abundant carbonaceous detritus; siltstone, weathers medium grayish brown, forms cliff with shale-forming recesses in cliff.	10.5	10.5
6	Covered interval, possibly shale or siltstone, forms slope.	8.8	19.3
5	Sandstone interbedded with silty sandstone, medium dark gray, weathers medium light pale yellow orange, fine grained, intensely bioturbated, most bedding destroyed due to bioturbation, hummocky stratification, flat stratification, bioturbation decreases near the top of the unit, forms ledges and cliffs.	6.5	25.8
4	Covered interval covered with talus from above, soil medium light yellow orange, probably silty shale or siltstone, forms slope.	5.3	31.1
3	Sandstone, medium light brownish gray, weathers medium light orange yellow, fine grained, thick to very thick bedded, at 8.1 m are ripple marks, zones of bioturbation, burrows include <i>Ophiomorpha</i> , hummocky stratification.	7.5	38.6
2	Interbedded sandstone and silty sandstone, medium light gray, weathers medium light pale yellow orange, botryoidal weathering, probably highly bioturbated, thin to medium bedded with siltstone laminated partings, occasional hummocky beds, forms cliff—sandstone forms siltstone, forms recesses in cliff.	7.9	46.5

#### Base of the Blackhawk Formation and top of a Mancos Shale tongue

	Total thickness of the Spring Canyon Member of the Blackhawk Formation		46.5
1	Covered interval, covered with talus and debris from above, where not covered, soil is medium light bluish gray, about 15 m from	136.0	136.0

#### Top of Star Point Sandstone, Panther Sandstone tongue, base of Mancos Shale tongue

	Total thickness of Mancos Shale tongue		136.0
2	Sandstone, medium dark gray, weathers medium light orange yellow, very fine grained, disseminated organic material, many burrows that are 0.5 to 1 cm in diameter, horizontal and vertical smooth tube burrows <i>Ophiomorpha</i> , forms cliff.	6.0	6.0
1	Sandstone interbedded sandy siltstone, medium light gray, weathers medium light pale yellow orange, fine grained, 2% particulate organic material, ripple marks in laminated sandy siltstone, upper 0.4 m is bioturbated, burrows 0.5 cm to 1 cm long, smooth tube-type burrows, minor hummocky stratification, forms cliff.	9.3	15.3

#### Base of the Star Point Sandstone and top of the Mancos Shale

	Total thickness of the Star Point Sandstone, Panther Sandstone tongue		15.3
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#### Mancos Shale

The section was measured in the central part of the area at Coal Creek. Only a partial section was measured. Starting point was near the southern boundary of the quadrangle 1 km due west of bridge crossing a dry wash. The section was started at the base of a prominent Mancos bluff (SE <sup>1</sup>/<sub>4</sub>, SW <sup>1</sup>/<sub>4</sub>, section 9, T. 14 S, R. 11 E).

7	Covered interval, covered with pediment gravels, slope wash, and stream alluvium, forms slope.	460.0	460.0
6	Siltstone, sandy, dolomitic, medium gray, weathers medium orange brown, limonite stained, abundant organic material forms ledge.	.3	460.3
5	Covered interval, soil is bluish gray, probably medium dark gray siltstone and silty shale, forms slope.	10.7	471.0
4	Sandstone, silty, calcareous, medium grayish brown, weathers medium light gray orange, very fine grained, small scale cross-bedding, ripple marks, echino-	0.15	471.15

	derm mold, burrows 6 mm in diameter, parallel to bedding and vertical, forms ledge.		
3	Covered interval, same as unit 1.	9.9	481.1
2	Siltstone and sandstone, calcareous, medium gray, weathers medium light gray, sandstone weathers medium light pale yellow orange, disseminated organic material, fine grained, 5% lithic fragments, minor bioturbation, burrows small—less than 3 mm in diameter, forms ledge.	0.5	481.6
1	Covered slope, covered with slope wash, probably medium blue gray shale and silty shale. Partial thickness of the Mancos Shale	81.9	563.5
			563.5

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