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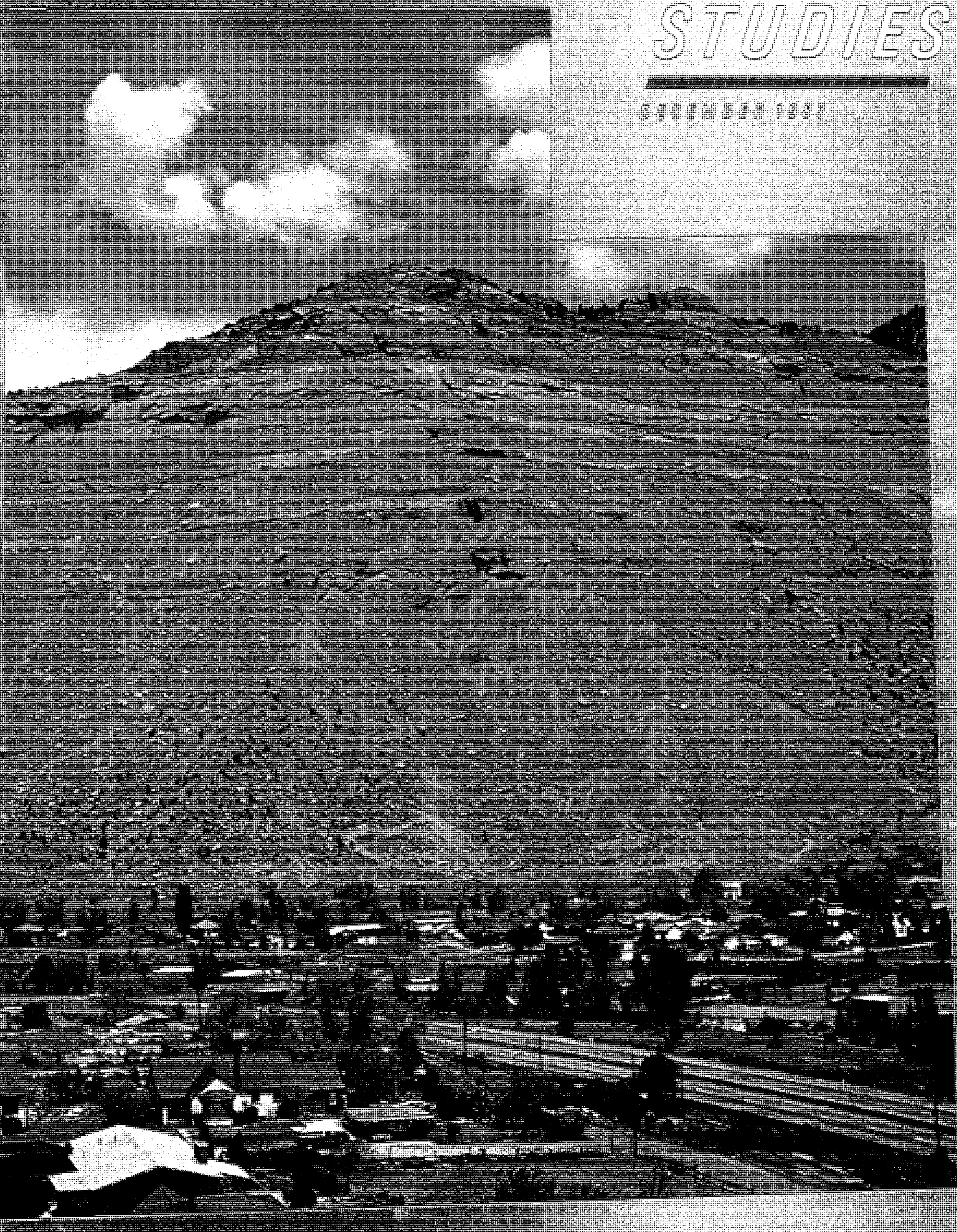

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Cover: Cretaceous coal-bearing rocks near Price, Utah

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Geology of the Standardville $7^1/_2'$ Quadrangle, Carbon County, Utah

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ABSTRACT

Exceptionally good exposures of Late Cretaceous and early Tertiary rocks in the western Book Cliffs area near Helper, Utah, allow analysis of nearshore clastic sediment. These cyclic deposits exhibit a prograding clastic shoreline sequence of open-marine and prodelta, lower shore face, upper shore face, foreshore, and fluvial coastal plain environments.

The Mancos Shale is an organic, silty shale interrupted regularly by tongues of fine- to medium-grained sandstone that thin eastward. The Garley Canyon and Emery Sandstones are the two main sandstone members in this quadrangle, but thinner sandstones, which indicate minor pulses of deltaic progradation, also crop out in the area. The Dempseyville, Bull Point, and Wildcat Canyon Sandstones are the three most prominent of these minor tongues and are here proposed as new members of the Mancos Shale.

The coal-bearing Blackhawk Formation is also well exposed within the area of study and was subdivided for mapping into the Spring Canyon Sandstone, mudstone 1, Aberdeen Sandstone, mudstone 2, Kenilworth Sandstone, and mudstone 3–4 members. It is interpreted as a wave-dominated delta complex. Evidence indicates that coal-forming swamps were situated directly upon beach ridge topography. Economically important coals include the Spring Canyon A sub 3, B sub 2, and C sub 1 and the Castlegate "A," "B," "C," Kenilworth or Castlegate "D" seams. Several of these coals are observed to pinch out westward (landward) within the area of study. This stratigraphic interplay between terrestrial sedimentation and swamp environments provides details for refining coal exploration models.

Regional thickness variations in Upper Cretaceous and lower Tertiary formations indicate crustal uplift associated with the San Rafael Swell may have begun as early as Price River time.

INTRODUCTION

The Standardville $7^1/_2'$ Quadrangle includes part of the Book Cliffs on the eastern flank of the Wasatch Plateau and has been the site of coal mining activities for nearly 90 years. Despite the long history of coal-related geologic interest, no detailed maps or review of the complete stratigraphic succession have been published for the Standardville area.

The principal objectives of this study are to document and interpret the exposed and subsurface geology of the Standardville $7^1/_2'$ Quadrangle by producing a detailed and accurate map of formations and members exposed in the quadrangle and by analyzing and correlating measured stratigraphic sections and subsurface drill data of the Upper Cretaceous units. Because the Standardville Quadrangle has great coal reserves, special emphasis has been placed upon interpretation of paleoenvironments and economic potential of coal-bearing units. In addition, because excellent exposures in the quadrangle allowed detailed subdivision of the upper part of the Mancos Shale, a modified stratigraphic nomenclature has been proposed for this formation.

LOCATION AND ACCESSIBILITY

The Standardville $7^1/_2'$ Quadrangle is on the northeast margin of the Wasatch Plateau in Carbon County, Utah, eight kilometers northwest of Price and immediately west of Helper (fig. 1).

U.S. 50 passes through the northeast corner of the Standardville Quadrangle and continues south immediately east of the quadrangle for nearly its entire length. Utah 139 cuts east–west across the southern third of the

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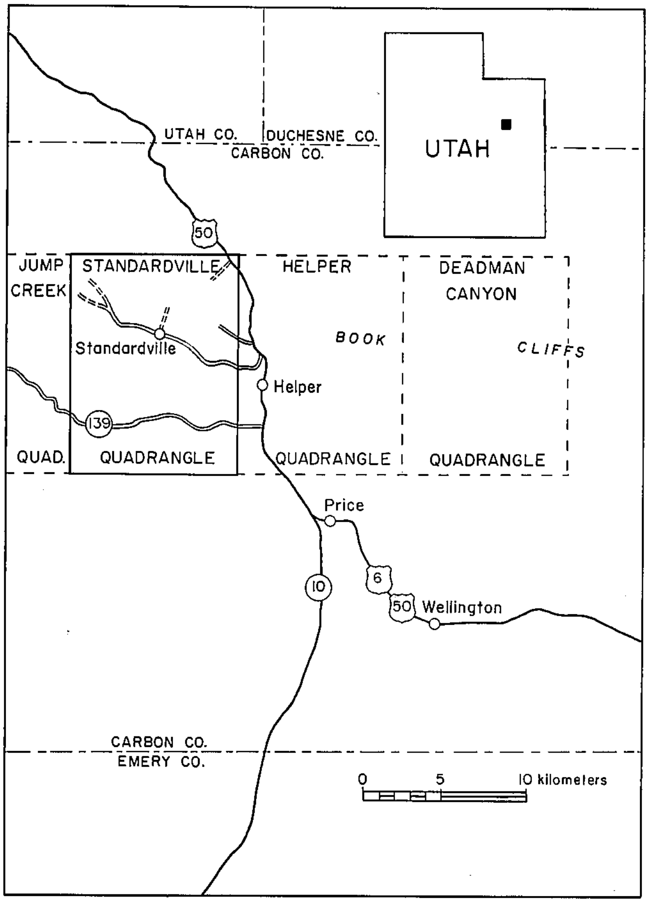

FIGURE 1.—*Index map showing location of the Standardville Quadrangle.*

quadrangle, and a paved two-lane road leads northwestward from Helper up Spring Canyon to Standardville and to several abandoned coal mines beyond. Numerous unimproved jeep roads provide access to other parts of the area. Access within the quadrangle is good, but direct passage from the northern half to the southern half of the quadrangle is entirely restricted by the formidable Book Cliffs.

PREVIOUS WORK

Coal-bearing rocks of the Book Cliffs have been the subject of geologic studies for over eighty years (Clark 1928, Gale 1910, Lupton 1916, Richardson 1909, Spieker 1931, Taff 1905). More recently, Balsley (1982); Fisher, Erdmann, and Reeside (1960); Howard (1966b); and Young (1955, 1966) have investigated the Cretaceous and Tertiary units of the area.

In his initial study of the economic geology of the Castlegate, Wellington, and Sunnyside 15' Quadrangles, Clark (1928) described the general structure and stratigraphy of the area and differentiated the section into four main units: Mancos Shale, Mesaverde Group, Wasatch Formation, and Quaternary deposits. He mapped these units, along with outcrops of the major coal seams, at a scale of 1:62,500 and gathered coal thickness data from outcrops throughout the area. Later, Doelling (1972) reevaluated the economic resources of the area and described the coal-bearing and associated rocks. Walton (1955, 1959) emphasized the geologic structure and gas potential in this and surrounding areas. Marley, Flores, and Cavaroc (1979) and Bunnell (in press) studied the economically important coal-bearing sequences. Cobban and Reeside (1952), Flores (1979), Hale (1959), and Weimer (1960) completed regional stratigraphic studies of the Upper Cretaceous and Tertiary rocks.

Geologic mapping and stratigraphic studies have been done on the nearby Soldier Summit 15' Quadrangle (Moussa 1965), the Deadman Canyon 7½' Quadrangle (Nethercott 1986), and the Scofield 7½' Quadrangle (Knowles 1985). Similar studies of the Jump Creek 7½' Quadrangle (Hansen in press) and the Helper 7½' Quadrangle (Russon 1987) are currently in progress.

METHODS AND MATERIALS

Contacts of formations and members and coal outcrops were mapped on aerial photographs (scales 1:20,000 and 1:31,000) and then transferred to a topographic base map (scale 1:24,000). Stratigraphic sections were measured using a 1.5 m Jacob's staff. The term mudstone has been used in the text for massive fine-grained rocks, and the term shale refers to fissile, fine-grained rocks. Mudstone members of the Blackhawk Formation include deposits of shale, coal, and sandstone, as well as mudstone. They have been differentiated from the major sandstones because of their general slope-forming habit compared with the massive cliffs of the sandstone units. Channel samples of the major coal seams, which were taken at various locations within the quadrangle, will be analyzed by Utah Geological and Mineral Survey personnel during further detailed study of the coal in this area.

ACKNOWLEDGMENTS

Thanks go to Dr. J. Keith Rigby for help and encouragement as thesis chairman, and to Drs. Lehi F. Hintze and Wade E. Miller as thesis committeemen. Appreciation is expressed to the Utah Geological and Mineral Survey for their help in funding and reviewing this project, and to Laine Adair and Price River Coal Company, who aided considerably with subsurface and coal data. Drs. E. Blair Maxfield and Myron G. Best graciously gave of their expertise in the fields of Cretaceous foraminifera and igneous petrology when help was needed. Special thanks also goes to my wife, Linda, without whose constant support this study would never have been completed.

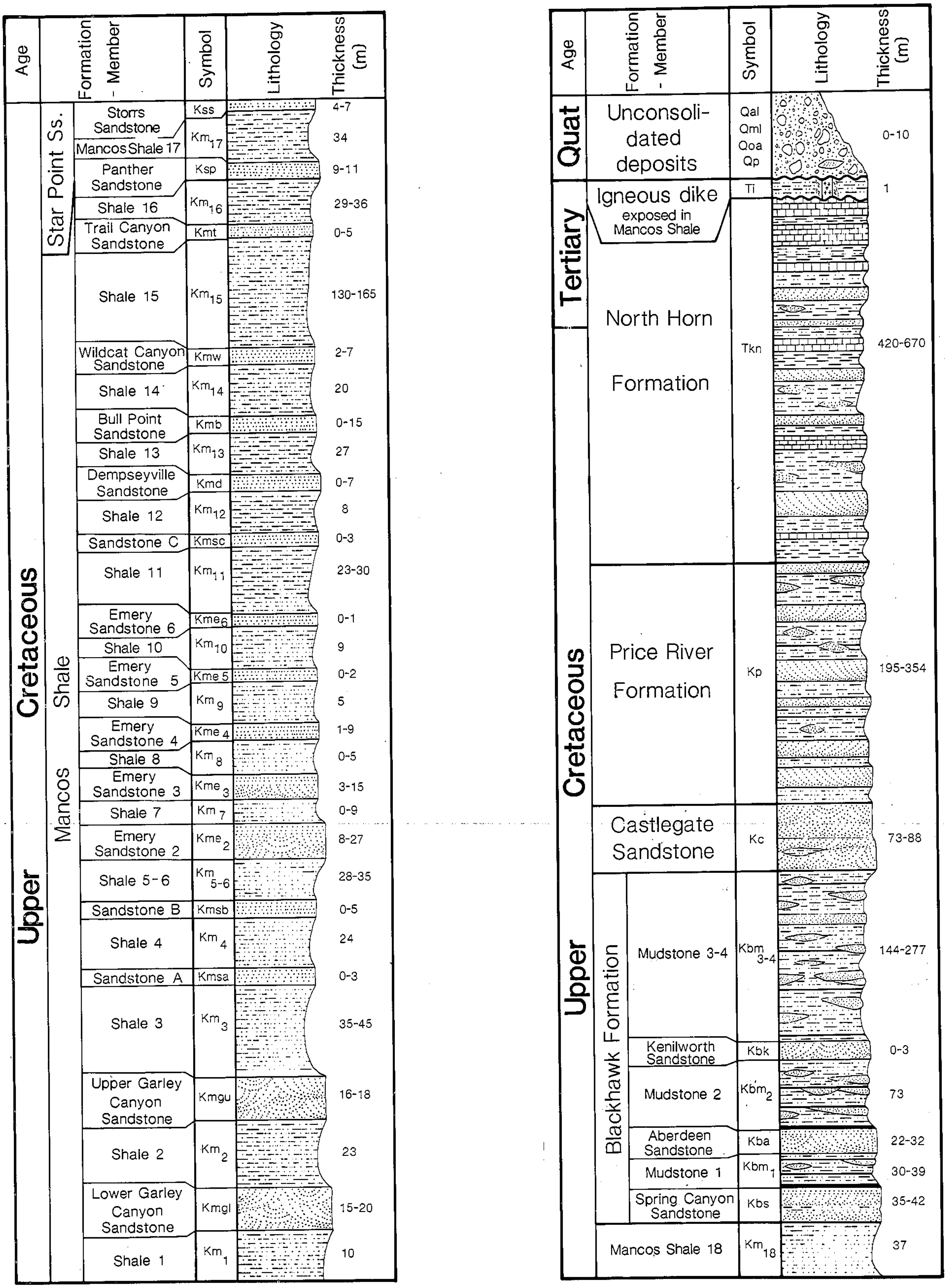

FIGURE 2.—*Generalized stratigraphic section of units exposed in the Standardville Quadrangle.*

STRATIGRAPHY

GENERAL STATEMENT

Bedrock units exposed within the Standardville 7½′ Quadrangle are almost entirely of Late Cretaceous age (figs. 2 and 3). They range from the upper Mancos Shale, the oldest unit in the area, to the lower part of the North Horn Formation. The Mancos Shale is locally overlain by the the Star Point Sandstone. Above this, the Blackhawk Formation, Castlegate Sandstone, and Price River Formation occur in ascending order. Regionally, these units grade eastward into Mancos Shale. The Price River Formation is overlain by the North Horn Formation, only the lower part of which is preserved in the quadrangle. Contacts between these formations are conformable except for a possible disconformity between the Blackhawk Formation and the Castlegate Sandstone. A Tertiary igneous dike crops out in the southeast corner of the quadrangle. Unconsolidated Quaternary deposits in the area include stream alluvium, weathered Mancos Shale lag, and pediment gravel. About 2000 m of Upper Cretaceous strata are exposed within the Standardville Quadrangle.

Fieldwork for this study was done concurrently with studies in the Jump Creek Quadrangle (Hansen in press) and the Helper Quadrangle (Russon 1987). For correlative purposes, stratigraphic units were compared on a three-quadrangle basis (fig. 4).

LITHOLOGIC RELATIONSHIPS OF FACIES I–IV

One of the obvious characteristics of the Upper Cretaceous stratigraphy in the Standardville Quadrangle, and the Book Cliffs in general, is the repetition of lithologies. Balsley (1982), Spieker (1949), and Young (1957) have described these rhythmic facies in detail. This cyclicity is attributed to lateral migration of depositional facies associated with a shifting shoreline. Young (1957, p. 1762–64) suggested that shifts in shorelines were associated with the episodic fall of sea level attributed to pulsating basin subsidence. Spieker (1949) concluded that subsidence of the basin was probably associated with uplift of the Mesocordilleran landmass in the west, which supplied the clastic sediments to the subsiding basin.

A complete cycle of sedimentation includes (1) basin subsidence with fairly rapid westward transgression of the sea and deposition of a marine shale, (2) formation of a barrier beach or bar at the time of maximum transgression and progradation of this clastic barrier seaward into a relatively static basin, and (3) development of a swamp or marshland landward of the barrier (Young 1957, p. 1764–65). This may be followed by continued subsidence initiating another complete cycle produced by pulses of sedimentation, or, if subsidence is only minor, deposits of the previous cycle may be modified slightly and stacking of one sandstone tongue on another would occur. If several minor pulses of deposition occur in succession, a thick coal seam may develop behind a nearly static barrier (Young 1957, p. 1766).

Such events are each recorded in the stratigraphic record by a distinctive facies pattern. Balsley (1982) described these patterns within the Blackhawk Formation and divided them into the prodelta, lower shore face, upper shore face, foreshore, and lagoonal facies. In addition to these five facies, he described sediments associated with distributary channels, distributary mouth bars, shallow-water turbidites, and tidal systems. Nethercott (1986) used this system in describing the Blackhawk Formation in the area of Deadman Canyon, east of the Standardville Quadrangle. A modified version of Nethercott's lithologic units, or facies I–IV, which correspond to the prodelta through foreshore facies of Balsley (1982), will be utilized in this report to describe sandstone members of the Mancos Shale, Star Point Sandstone, and Blackhawk Formation (fig. 5).

Facies I is composed chiefly of thin-bedded, dark gray siltstone, interbedded with silty shale and fine-grained sandstone. Individual beds range from 3 to 30 cm thick, and thickness generally increases upward. Siltstone and shale beds contain abundant carbonaceous detritus, which gives the rocks a dark gray color. The shales contain varying amounts of volcanic ash. Parallel lamination is the typical primary sedimentary structure in the shales and siltstones, but small-scale cross-laminations, wave ripple marks, and hummocky cross-stratification occur in the sandstones. Macrofossils are only rarely found in this facies, but marine microfossils are quite common (Beard 1959). Bioturbation in facies I varies greatly, ranging from minimal to intense. Morphology of trace fossils within siltstones is generally obscured, but recognizable polychaete annelid burrows are common in the sandstones. Upper and lower contacts of facies I are both gradational and are defined on percentage of sandstone, siltstone, and shale. Outcrops of these rocks vary from weathered grayish slopes, similar to badland topography carved on the Mancos Shale, where siltstone and shale are dominant, to a semiresistant ledge where siltstone and sandstone dominate.

This facies corresponds to the prodelta and transition zone environments of Balsley (1982, p. 76), and is situated between the lower shore face and open-marine environments. Sedimentation in the prodelta area is dominated by the vertical precipitation of fine, suspended detritus that bypassed the delta front, and is below effective wave base. The transitional zone, however, is subject to current action and horizontal accretion of clastic sediments (Balsley 1982).

Facies II is composed of calcareous, fine-grained quartz sandstone with individual beds ranging from 15 to 200 cm

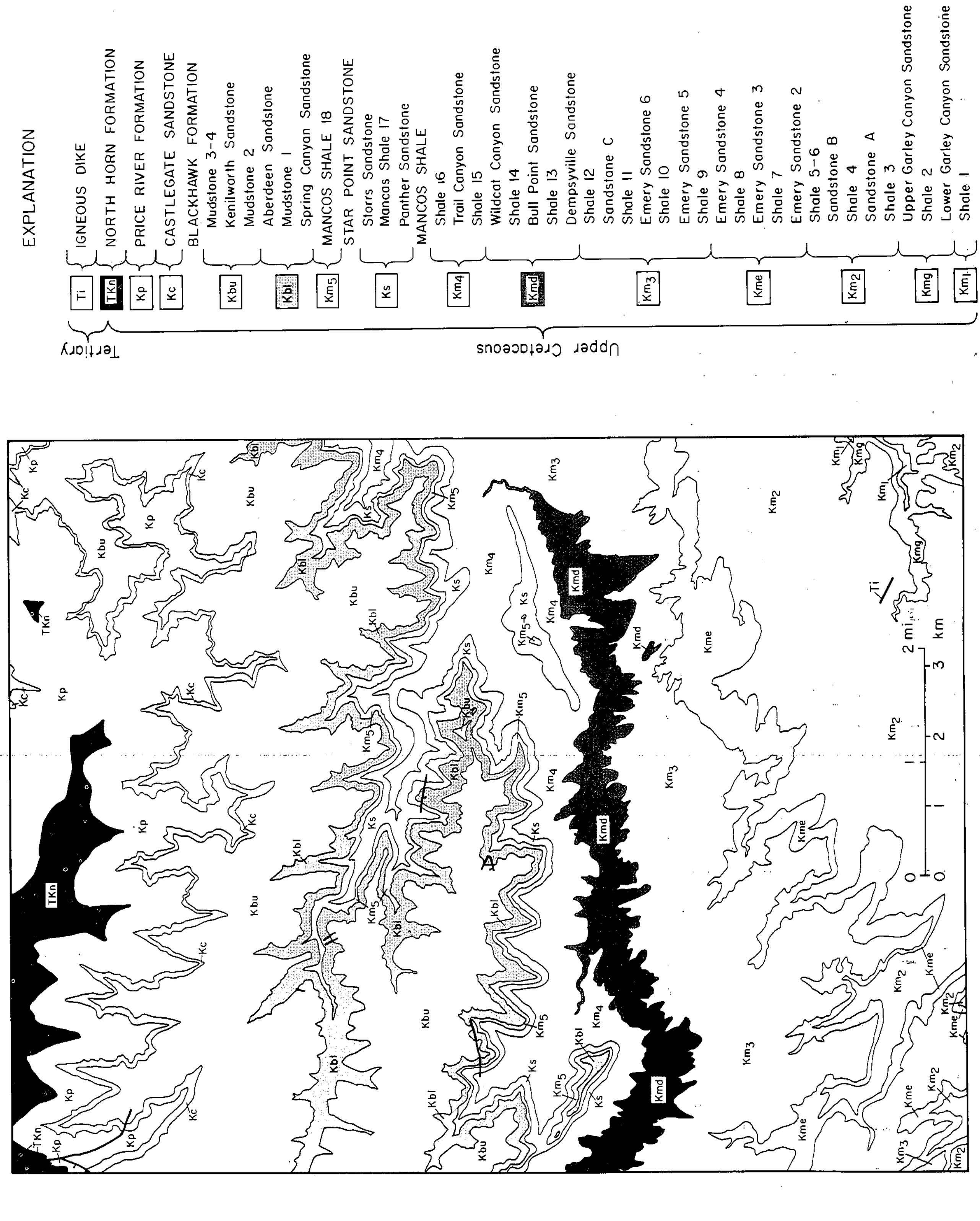

FIGURE 3.—*Simplified bedrock geologic map of the Standardville Quadrangle.*

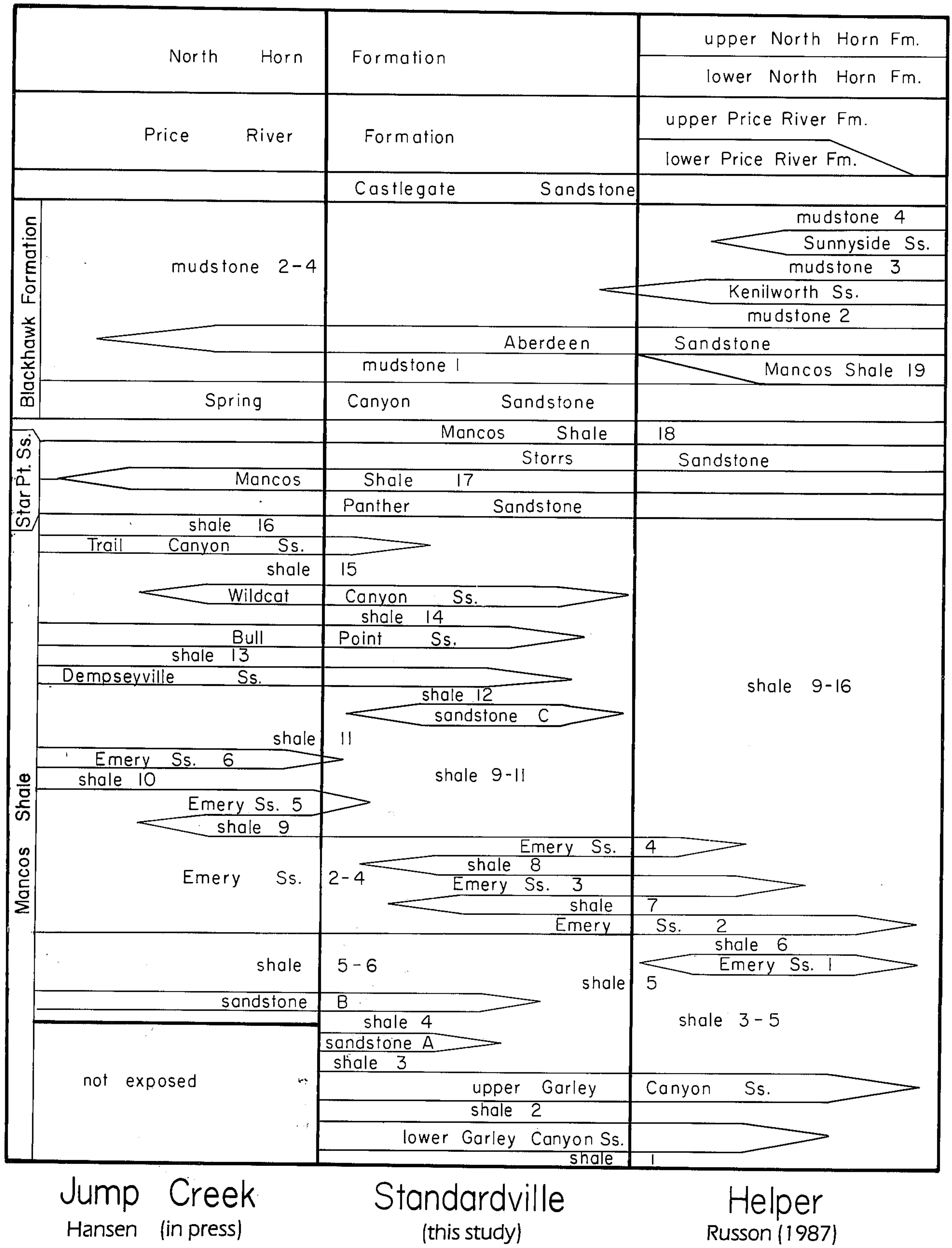

FIGURE 4.—*Panel diagram illustrating the stratigraphic relationships of formations, members, and tongues exposed in the Jump Creek, Standardville, and Helper 7½′ Quadrangles. Thicknesses in diagram do not represent true unit thicknesses.*

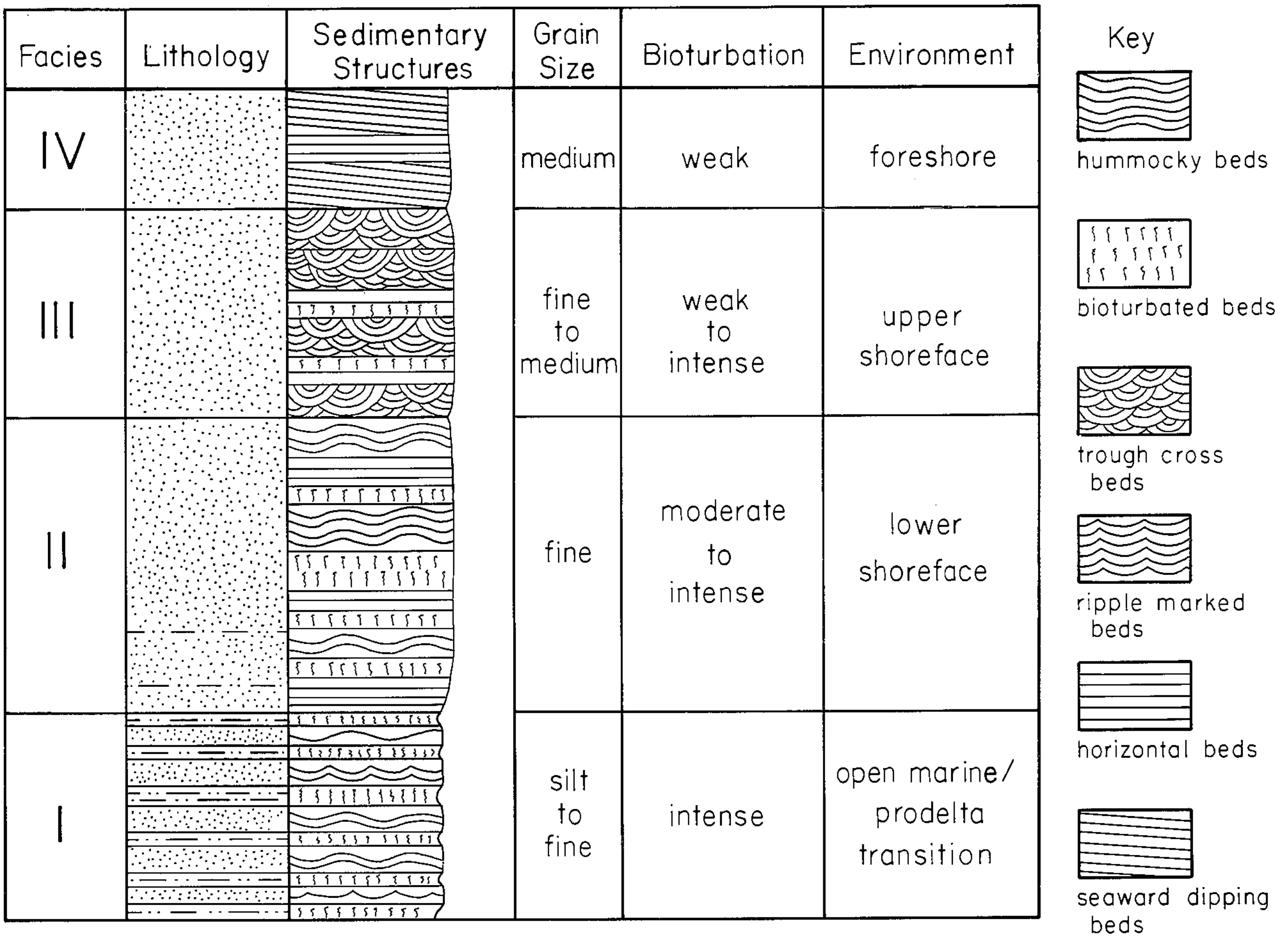

FIGURE 5.—*Table illustrating lithology, sedimentary structures, grain size, bioturbation, and environment of deposition of facies I–IV (modified after Nethercott, 1986).*

thick. As in facies I, there is a general tendency for an upward increase in grain size and textural and compositional maturity. Outcrops of this facies form yellowish gray to grayish orange ledges. Primary sedimentary structures of facies II are more diversified and complex than those of any other facies. Wave ripples occur occasionally on the tops of beds, but the facies is dominated by parallel lamination and hummocky cross-stratification (fig. 6). The lower part of the facies is typified by hummocky stratification, but the upper part generally shows interbedded plane parallel lamination and hummocky stratification. A varying amount of cross-stratification is also present throughout the facies.

No shelly fossils of any kind were found by the author in rocks of this facies. Balsley (1982) suggested that the unfossiliferous nature may be due to postdepositional leaching. The trace fossil assemblage, however, is much more diversified than that of facies I. *Ophiomorpha, Aulchnites, Chondrites, Asterosoma, Teichichnus, Gyrochorte, Cylindrichnus,* and *Terebellina,* along with annelid worm burrows, are the more common trace fossils in this facies (Nethercott 1986; Balsley 1982, p. 83). Commonly, each bed shows vertical increase in bioturbation with the top being intensely burrowed.

Facies II represents the lower shore face environment. Deposition in this area is dominated by violent but infrequent storm wave action. These storm events scoured and reworked the upper part of previously deposited sediments into low swales and hummocks (fig. 6). The tops of these hummocks were then often reworked by normal, fair-weather wave action and filter feeding bioturbators (Balsley 1982, p. 90–96).

Facies III is characterized by medium orange gray to light gray, fine- to medium-grained sandstone. Sand grains are primarily quartz, but small percentages of carbonaceous material, black chert, and feldspar are also present. As in facies II, this facies is generally very resistant, and forms steep and somewhat rounded cliffs. High-angle cross-stratification is the distinguishing structural feature of this facies. Sets are typically 10 to 50 cm thick

FIGURE 6.—*Hummocky stratification in facies II beds of the Spring Canyon Sandstone in Gilson Gulch, SE 1/4, SE 1/4, section 8, T. 13 S, R. 9 E.*

and 20 to 70 cm long. Bioturbation is rare to moderate, with *Ophiomorpha* and cylindrical burrow structures present. The lower contact with beds of facies II is gradational to sharp while the upper contact with facies IV is almost always sharp.

The depositional environment represented in facies III is the high-energy, shallow-water upper shore face (Harms and others 1975, p. 89). In the upper shore face environment, breaking waves and longshore currents are dominant (Balsley 1982, p. 90–96).

Facies IV, when present, is perhaps the most easily recognized of the four facies. It is characteristically a light gray, medium-grained quartzose sandstone. The distinctive light gray "white cap," however, often extends below facies IV into the uppermost part of facies III. Primary sedimentary structures within this facies are almost wholly gently dipping parallel laminations. These parallel laminations dip seaward at 2 to 6 degrees, but are often obscured in the top 20 to 50 cm of the facies by abundant root markings. Trace fossils, however, are only rarely seen lower in the facies. The upper contact of facies IV is sharp, and when seen from a distance, looking down strike of the laminations, it has a gently undulating top.

Wave wash and backwash are the major currents within the foreshore zone, represented by facies IV (Balsley 1982, p. 114–19; Harms 1979, p. 98; Reading 1978, p. 147). The top of this facies corresponds to the landward extent of clastic shore zone deposition, and its wavy surface corresponds to crests and troughs of beach ridges on a strand plain.

Generally, coal-bearing backswamp or lagoonal deposits culminate progradation of the shoreline. The complexity and diversity of these deposits, however, hinder a generalized description. Each of these facies will be discussed individually.

In a given sandstone tongue, a complete sequence of facies I through IV may not be present. Facies IV is commonly not present, and repeated sequences of facies I and II or II and III have been observed.

CRETACEOUS SYSTEM

Mancos Shale

The Mancos Shale is the oldest exposed unit within the Standardville Quadrangle. It is entirely of Late Cretaceous age.

Overall thickness of the Mancos Shale is between 1432 and 1539 m in the Price area (Clark 1928), but only the upper 762 m of the Mancos Shale crops out in the Standardville Quadrangle. In addition to this, two shale tongues (32 and 38 m thick) also occur higher in the section (fig. 4). The formation is predominantly silty shale and fine- to medium-grained sandstone, but a few thin lenses of limestone also occur. Except for microfossils, no fossils were found in the Mancos Shale. This is probably due to the weathered condition of the outcrop, but also indicates a general sparsity of life in the Mancos Sea. For detailed mapping in the Standardville Quadrangle, the Mancos Shale has been subdivided into 15 sandstone and 18 shale units (fig. 4). The Mancos Shale is 73% shale and 27% sandstone in the west part of the quadrangle, compared to 89% shale and 11% sandstone in the east.

Shale members. Shale members of the Mancos Shale consist of dark bluish gray to dark brownish gray silty shale and become increasingly silty toward the top of the formation. These shaly units are locally interbedded with abundant thin sandstone and rare thin limestone lenses. Beds of septarian nodules are occasionally found. Away from the Book Cliffs escarpment, the shale weathers to form gentle slopes between cuestas held up by gently dipping minor sandstones and are often covered by deposits of silt and fine-grained sand, which form as a lag deposit when finer sediments of weathered Mancos Shale are winnowed away. Where the shales are protected by major resistant sandstones, as in the Book Cliffs escarpment, the shales erode to steep badland topography, and layers in which the shale is bentonitic produce slopes that exhibit a lumpy "popcorn" appearance.

Foraminifera were collected from an exposure of shale members 3–6 at NE 1/4, SE 1/4, section 34, T. 13 S, R. 9 E. They are common in these shales, but preservation is not good. These include *Trochammina wickendeni*, *Ammobaculites fragmentarius*, *Ammodiscus* sp., *Gaudryina bentonensis*, *Dorothia oxycona*, *Anomalina tennesseensis*, *Citharina* sp., and *Haplophragmoides rudis*. A more definitive age than Upper Cretaceous cannot be deter-

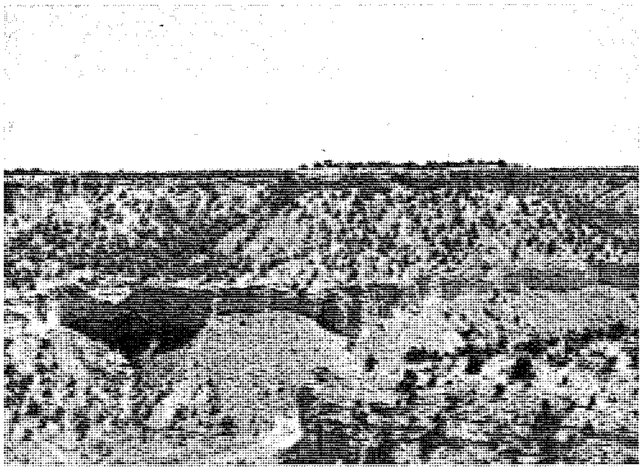

FIGURE 7.—*A view south of the lower and upper Garley Canyon Sandstones in section 2, T. 14 S, R. 9 E.*

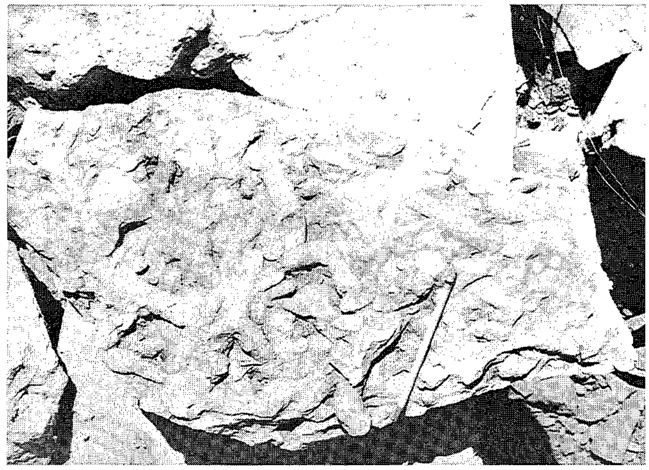

FIGURE 8.—*The trace fossil* Ophiomorpha *on the upper side of a bed within the facies II of the upper Garley Sandstone, NE ¼, NE ¼, section 2, T. 14 S, R. 9 E.*

mined on the basis of these microfossils because of the long stratigraphic ranges of these species (E. Blair Maxfield written communication 1983).

The shale portion of the Mancos Shale was subdivided into 18 members or tongues. Many of these coalesce in the eastern part of the quadrangle to form thick, uninterrupted sequences of shale, and several tongues pinch out between sandstone units westward within the quadrangle (fig. 4). Shale members 17 and 18 intertongue with the Star Point Sandstone and Blackhawk Formation.

In the Castle Valley area, Spieker and Reeside (1925) referred to the shale below the Emery Sandstone Member as the middle shale member and that above as the upper shale member. At times these units have been termed Blue Gate Shale and Masuk Shale Members (Hintze 1973, p. 142–43); however, no direct correlation has been made from their type localities in the Henry Mountains (Maxfield 1976, Smith 1983).

Shale and siltstone of the Mancos Shale were deposited in a muddy, shallow marine seaway beyond the sand-mud transition line (Young 1955). Spieker (1949) suggested that environmental conditions were not conducive to limestone deposition.

Garley Canyon Sandstone Member. The Garley Canyon Sandstone was subdivided for mapping into lower and upper Garley Canyon sandstones that are separated by shale member 2 of the Mancos Shale (fig. 7). These were first described by Clark (1928) in Garley Canyon. The Garley Canyon Sandstone crops out only in the extreme southeast corner of the Standardville Quadrangle.

Both Garley Canyon sandstones are composed of facies I and II, with facies II beds more prominent to the north than to the south. Facies I sequences sometimes make up more than half of the thickness of the sandstones and range from 7 to 10 m. The remaining thickness is made up of facies II. Bioturbation is locally extensive at the tops of beds within the facies II sequence (fig. 8). Slumping has occurred in the upper Garley Canyon Sandstone (fig. 9). Orientations of these slump features indicate that the direction of depositional dip was to the south or southeast.

Garley Canyon Sandstone probably represents an oblique section of the distal edges of prograding delta lobes. The sandstone-shale-sandstone sequence may be due to transgression and regression of the Mancos Sea, or may signify a shift in depositional areas due to a rapid change in the distributary channel.

Sandstone A and B Members. Sandstones A and B are thin units that occur 35 to 45 m and 60 to 70 m, respectively, above the upper Garley Canyon Sandstone (figs. 4 and 10). They are separated by the 24-m-thick shale member 4. Sandstone B is overlain by shale member 5–6, which is 28 to 35 m thick. These two sandstone tongues may coalesce with the Emery Sandstone Member some distance to the southwest in the subsurface.

Sandstone A reaches only 3 m thick and pinches out near the center of the quadrangle. Westernmost exposures of sandstone A in the quadrangle consist of 2.5 m of facies I and 0.5 m of facies II. These gradually grade eastward into Mancos Shale.

Maximum thickness of sandstone B in the quadrangle is 5 m. The lower 3.5 m consist of facies I, and the overlying 1.5 m is made up of facies II beds. No pinch out of this sandstone was observed because it is buried under Mancos Shale lag deposits in the central part of the quadrangle, but it appears to extend farther to the east than sandstone A.

Emery Sandstone Member. The Emery Sandstone is the thickest sandstone member of the Mancos Shale in

FIGURE 9.—*Large slumps within the upper Garley Canyon Sandstone in NW 1/4, NW 1/4, section 3, T. 14 S, R. 9 E. Overlying beds of the Mancos Shale are horizontal. The rod standing near the lower left gully is 1.5 m high.*

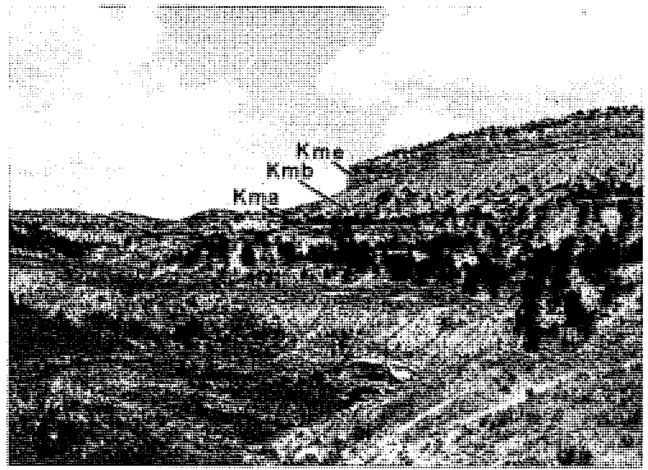

FIGURE 10.—*A view up North Fork Gordon Creek, NW 1/4, section 7, T. 14 S, R. 9 E. The cliff-forming unit is Emery Sandstone 2–4 (Kme). Sandstones A (Kma) and B (Kmb) are barely visible on the east side of the canyon, and terraces of older alluvium (Qoa) can be seen on both sides of the canyon.*

the Standardville Quadrangle. It is composed of five sandstone tongues separated by four shale tongues (fig. 4). At the western edge of the quadrangle, the lowest three tongues, Emery Sandstone 2, 3, and 4, coalesce to form a 56-m-thick sandstone unit. These three sandstone tongues are traceable across the entire quadrangle. However, the upper two tongues, 5 and 6, occur only near the western edge of the quadrangle. Emery Sandstone 5 and 6 tongues coalesce with 2 through 4 westward in the Jump Creek Quadrangle as intertonguing shales pinch out. The lowest tongue, Emery Sandstone 1, occurs only to the east in the Helper Quadrangle (fig. 4). Thicknesses of shales between individual Emery Sandstone tongues range up to 9 m.

Emery Sandstone 2–4, in the western part of the quadrangle, consists of a 12 m basal facies I, which is overlain by 3 m of facies II. These beds are overlain by 19 m of facies III, 6 m of facies II, and 16 m of facies III. Tongues 5 and 6 are composed almost entirely of facies I and have only a thin cap of facies II.

Eastward, the sandstone tongues thin and intertonguing shales thicken. Emery Sandstone 2, 3, and 4 tongues are 8, 3, and 1 m thick, respectively, at the eastern border of the quadrangle, and include only facies I and II. Facies II often does not form a continuous sheet at distal edges of these sandstone tongues. Rather, it pinches in and out to produce what superficially resemble channels (fig. 11). These lens-shaped sandstones probably originated where coarser-grained sediments were flushed out onto the soft muck of the Mancos Shale.

Uneven loading may have caused these heavier sands to form pillowlike features depressed into the underlying shale and siltstone. This type of sedimentary structure was also observed in other sandstones of the Mancos Shale higher in the section.

Sandstone C Member. Sandstone C is a thin sandstone lens that crops out for about 5 km along the base of the Book Cliffs escarpment in the central and eastern part of the quadrangle. It occurs 23 to 30 m above the Emery Sandstone 4 tongue. It has a maximum thickness of 3 m and is composed, in most places, entirely of facies I. Facies II occurs sporadically as lens-shaped pillow structures.

Dempseyville Sandstone Member. The Dempseyville Sandstone, named here for exposures near Dempseyville (also known as Coal City; see appendix), is the lowest of three sandstones that form a series of cuestas intermediate between the Emery Sandstone and the Star Point Sandstone at Bull Point (fig. 12). The Dempseyville Sandstone lies 31 to 38 m above the Emery Sandstone 4 tongue, and where Sandstone C is present, these two sandstones are separated by 8 m of shale (fig. 4). The Dempseyville Sandstone grades into Mancos Shale in the central part of the quadrangle.

The Dempseyville Sandstone ranges in thickness up to 7 m within the quadrangle. It is represented by facies I and II only, and the facies II beds exhibit pillow structures and smaller, subspherical, calcareous nodules that are 2 to 15 cm in diameter.

Bull Point Sandstone Member. The Bull Point Sandstone is the middle of the three cuesta-forming sandstones. It is here named for outcrops at Bull Point (see appendix). It is the thickest of these three sandstones and measures 15 m thick at its westernmost exposure in the

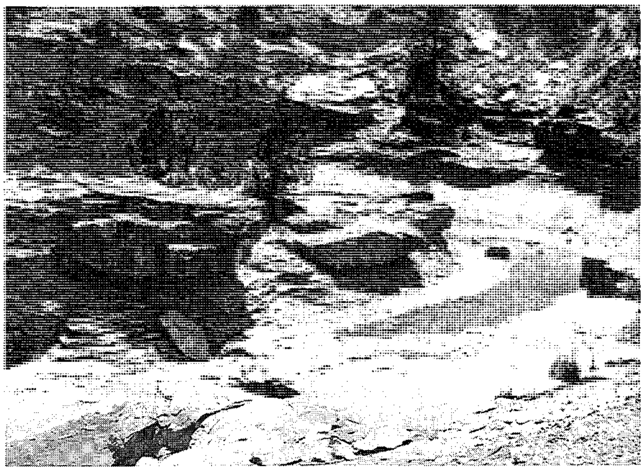

FIGURE 11.—*Pillow structures in Emery Sandstone 2 (SW ¼, SW ¼, section 27, T. 13 S, R. 9 E), which form as a result of coarse-grained sediments being dumped onto soft Mancos Shale, causing the overlying sediments to settle unevenly.*

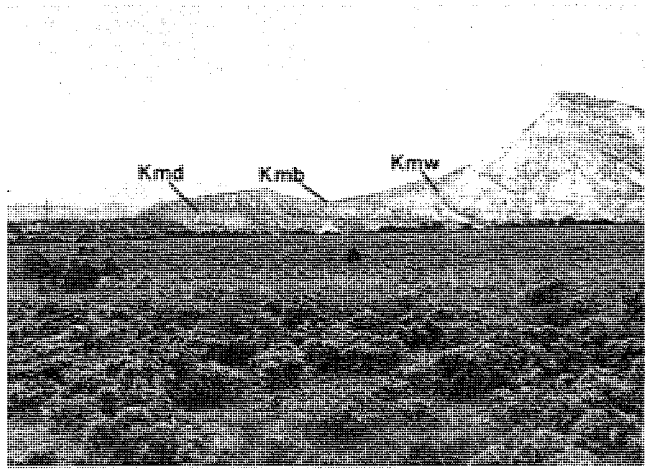

FIGURE 12.—*Bull Point to the northwest (section 25, T. 13 S, R. 8 E) showing the three cuestas that mark the newly named Dempseyville Sandstone (Kmd), the Bull Point Sandstone (Kmb), and the Wildcat Canyon Sandstone (Kmw).*

quadrangle. However, it pinches out eastward at approximately the same location as the underlying, and much thinner, Dempseyville Sandstone. About 27 m of shale separate these two sandstones. On the south flank of Bull Point, the Bull Point Sandstone comprises 9 m of facies I beds and an overlying 5 m of facies II.

Wildcat Canyon Sandstone Member. The upper cuesta-forming sandstone is here named the Wildcat Canyon Sandstone for good exposures at the mouth of Wildcat Canyon (see appendix). It is 20 m above the Bull Point Sandstone and ranges in thickness from 2 to 7 m.

This sandstone is the only one of the three that is not observed to pinch out in the quadrangle. The outcrop is covered beneath alluvium east of the mouth of Spring Canyon. However, it probably does not extend far past the eastern boundary of the quadrangle, for it has not been mapped in the Helper Quadrangle to the east (Russon personal communication 1984).

In the western part of the quadrangle, 130 to 165 m of shale separate the Wildcat Canyon Sandstone from the Trail Canyon Sandstone, and in the central and eastern part where the Trail Canyon Sandstone is not present, 159 to 201 m separate the Wildcat Canyon Sandstone from the Panther Sandstone. The Wildcat Canyon Sandstone is lithologically similar to the two sandstones below it and is made up of facies I and II.

Trail Canyon Sandstone Member. The Trail Canyon Sandstone, named by Hansen (in press), crops out on the west side of the quadrangle, high on the Book Cliffs escarpment, 29 to 36 m below the Panther Sandstone (fig. 4). It grades eastward into Mancos Shale about 3 km from the western edge of the quadrangle, but a silty "shadow" of this unit can be mapped the entire width of the quadrangle. This sandstone is probably no more than 5 m thick in the area, and is probably represented by facies I and II only. A more detailed description is given by Hansen (in press) from the Trail Canyon area in the Jump Creek Quadrangle to the west.

Star Point Sandstone

Spieker and Reeside (1925) named the Star Point Sandstone from prominent exposures at Star Point, southwest of Price, Utah. Clark (1928) proposed the Panther, Storrs, and Spring Canyon Tongues of the formation for outcrops in the Book Cliffs Coal Field in and near the Standardville Quadrangle (fig. 13). The Spring Canyon Tongue, however, was reassigned as the basal member of the overlying Blackhawk Formation by Young (1955). The age of the Star Point Sandstone is medial Montanan, based on fossils found by Clark (1928) and Spieker (1931); however, none were found in the study area.

Panther Sandstone Member. The Panther Sandstone was named for excellent exposures of the lower tongue of the Star Point Sandstone in Panther Canyon, a tributary of Price Canyon, just east of the Standardville Quadrangle (Clark 1928). Later, Howard (1966a) did extensive studies on the sedimentary facies and depositional environment of this unit within the Standardville Quadrangle and areas to the south and east. The Panther Sandstone ranges in thickness from 26 to 30 m within the quadrangle. It has a maximum thickness of 60 m in the Jump Creek area to the west (Hansen 1985) and pinches out between Mancos Shale tongues in the Book Cliffs about 22 km east of the Standardville Quadrangle.

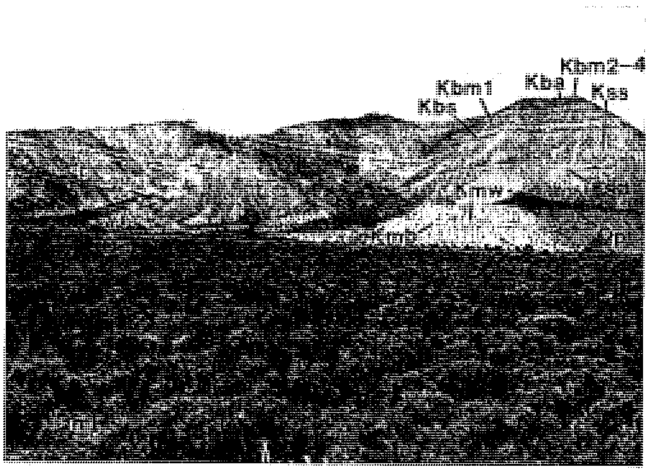

FIGURE 13.—*A view northward to the Book Cliffs (sections 19 and 20, T. 13 S, R. 9 E), and the units that make up the escarpment: Bull Point Sandstone (Kmb), Wildcat Canyon Sandstone (Kmw), Panther Sandstone (Ksp), Storrs Sandstone (Kss), Spring Canyon Sandstone (Kbs), mudstone 1 member (Kbml), Aberdeen Sandstone (Kba), and mudstone 2–4 member (Kbm2–4). Several surfaces of pediment gravel (Qp) and Mancos Shale lag (Qml) deposits can also be seen.*

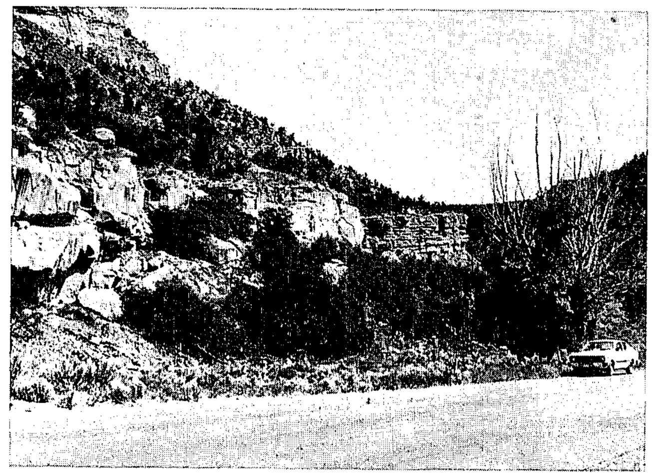

FIGURE 14.—*Oblique view of facies change in the Panther Sandstone looking down Spring Canyon from the mouth of Sowbelly Gulch (NE 1/4, section 16, T. 13 S, R. 9 S). The thick-bedded, cross-laminated facies in the foreground is in stark contrast with the large-scale cross-bedded facies in the distance.*

In Spring Canyon the Panther Sandstone exhibits a striking facies change (fig. 14). Eastern exposures consist of large-scale cross-bedded sandstone with beds having a primary depositional dip of 2 to 10 degrees to the southwest. Individual beds can be easily traced as they dip down through the unit and finally grade into the underlying Mancos Shale. Throughout most of the quadrangle, however, the Panther Sandstone has a massive appearance, but is in fact a medium-grained, cross-laminated sandstone. Both of these facies are underlain by mottled gray siltstone and sandstone typical of facies I. The Panther Sandstone is overlain and underlain by tongues of the Mancos Shale.

Sandstones of the large-scale cross-bedded facies, in Panther Canyon and in the eastern part of the Standardville Quadrangle, are fine- to medium-grained, and are interbedded with organic-rich silty shale. They are thin- to medium-bedded. Primary sedimentary structures include ripple marks and a variety of sole marks. Howard (1966a) studied these flow-directional sole marks within this facies and determined that paleocurrent directions were to the southwest and parallel the dip of the large-scale cross-beds. This facies grades laterally into facies I to the east and south. Westward, the large-scale cross-bedded facies has an erosional upper surface, and the facies pinches out altogether not far up Spring Canyon.

Above and westward of this eroded surface is the medium-grained sandstone facies that forms rounded cliffs. It is made up of medium-to-thick beds that are internally cross-laminated. Bioturbation is rare within this facies and is restricted to the top of the unit (Howard 1966a). Other erosional surfaces have been observed within this facies (fig. 15). The erosional surface between the two facies is quite evident on the south side of Spring Canyon near Sowbelly Gulch.

The large-scale cross-bedded facies of the Panther Sandstone in the eastern part of the quadrangle has been interpreted as the foreset cross-beds of a delta front sheet associated with a wave-dominated delta (Howard 1966a). The thick-bedded, cross-laminated facies to the west probably represents lateral migration of the distributary channel that has eroded through the abandoned distributary mouth-bar deposits as a result of progradation of the delta. The lower, mottled gray siltstone and sandstone facies that underlies the other two facies of the Panther Sandstone already discussed, corresponds to the prodelta and transition zone of facies I.

Storrs Sandstone Member. The Storrs Sandstone was named for rocks of the upper tongue of the Star Point Sandstone near the now-abandoned town of Storrs in Spring Canyon (Clark 1928). A tongue of the Mancos Shale, 29 to 36 m thick, separates this unit from the Panther Sandstone below. In the area of Wildcat Canyon, this Mancos Shale tongue consists of interbedded silty shale and numerous sandstone tongues, and pinches out about 10 km to the west, where the Storrs Sandstone rests directly on top of the Panther Sandstone. The Storrs Sandstone is 11 to 20 m thick in the quadrangle but thins rapidly eastward and pinches out about 5 km east of the Standardville Quadrangle.

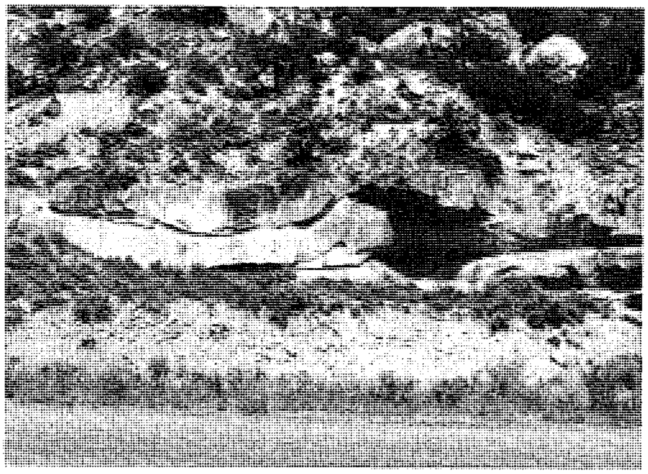

FIGURE 15.—*A view on the north wall of Spring Canyon of channeling in the thick-bedded, cross-laminated facies of the Panther Sandstone (NW 1/4, section 16, T. 13 S, R. 9 E).*

The Storrs member can be divided into two facies: an interbedded shaly siltstone and sandstone facies typical of facies I, and a medium-bedded, fine-grained sandstone facies. The sandstone facies compares favorably with facies II, but has much more cross-lamination than typically found in this facies. The lower, siltstone facies remains fairly consistent in thickness throughout the area, but the upper, sandstone facies is responsible for most of the westward thickening. In western exposures of the quadrangle, sandstone of facies III develops at the top of the Storrs Sandstone, and farther west, the development of a "white cap" of facies IV has been noted (Hansen in press).

Blackhawk Formation

The Blackhawk Formation was named by Spieker and Reeside (1925) for exposures west of Mohrland, Emery County, Utah, near the Blackhawk Mine (now King Mine No. 2). Originally, this included the sandstone, mudstone, and coal between the Spring Canyon Sandstone and the Castlegate Sandstone. The basal contact was placed at the lowest coal (Spring Canyon A sub 3 or Hiawatha seam) in the Wasatch Plateau. Later, Young (1955) included the Spring Canyon Sandstone in the Blackhawk Formation. He defined five members, each of which were made up of a basal littoral sandstone and an overlying unit of mudstone, shale, and coal. These members are the Spring Canyon, Aberdeen, Kenilworth, Grassy, and Desert Members. Maberry (1971) added the Sunnyside, lower mudstone, and upper mudstone members to the Blackhawk Formation in the area of Sunnyside. In the present study the littoral sandstones and overlying coal-bearing mudstone units were differentiated and mapped as separate members (figs. 2 and 4). Therefore, the members of the Blackhawk Formation present in the Standardville Quadrangle are the Spring Canyon Sandstone, mudstone 1, Aberdeen Sandstone, mudstone 2, Kenilworth Sandstone, and mudstone 3–4 (figs. 16 and 17). Since the Sunnyside Sandstone Member is not present in the quadrangle, mudstones 3 and 4 are undifferentiated, and because the Kenilworth Sandstone pinches out near the eastern edge of the area, throughout most of the quadrangle the uppermost part of the Blackhawk Formation is designated mudstone 2–4.

Within the Standardville Quadrangle, the thickness of the Blackhawk Formation ranges between 330 and 410 m. No overall thinning or thickening trend is apparent in the area. The formation thins gradually to the east of the quadrangle as lower sandstone members grade laterally into the Mancos Shale. To the south and west, however, its thickness remains uniform. Nethercott (1986) reported a thickness of 327 m at Coal Creek Canyon about 17 miles to the east. The Blackhawk Formation finally grades completely into Mancos Shale near Cisco, Utah (Young 1966, p. 16).

The Blackhawk Formation consists of two distinct lithologic packages: one composed of calcareous shale, siltstone, and sandstone, and the other made up of carbonaceous shale, mudstone, siltstone, sandstone, and coal. The first package was described in detail earlier as facies I–IV and is represented by the Spring Canyon Sandstone, Aberdeen Sandstone, and Kenilworth Sandstone Members. These major sandstones are easily traced in the field due to their cliff-forming nature and characteristic "white cap." The second lithologic package forms ledgy slopes between these major sandstones. They are composed of fine-grained, organic-rich clastic deposits and coal; therefore, they are generally covered. Thin-bedded, fine-grained sandstone ledges regularly interrupt these slopes. Rocks of this package are medium gray to dark gray brown, and produce well-preserved plant fossils. This lithologic package is represented by mudstone 1, mudstone 2, and mudstone 3–4 members. All of the economically important coal seams in the Standardville Quadrangle occur in the mudstone members of the Blackhawk Formation.

Wave-dominated deltas and associated environments were responsible for deposition of sediments in the Blackhawk Formation. Major sandstone tongues are considered to represent prograding delta front and nearshore marine deposits, while the mudstone units were deposited under terrestrial or terrestrial-marine transitional conditions.

The lower contact of the Blackhawk Formation is conformable and gradational with the underlying tongue of Mancos Shale that separates the Star Point Sandstone from the Blackhawk Formation.

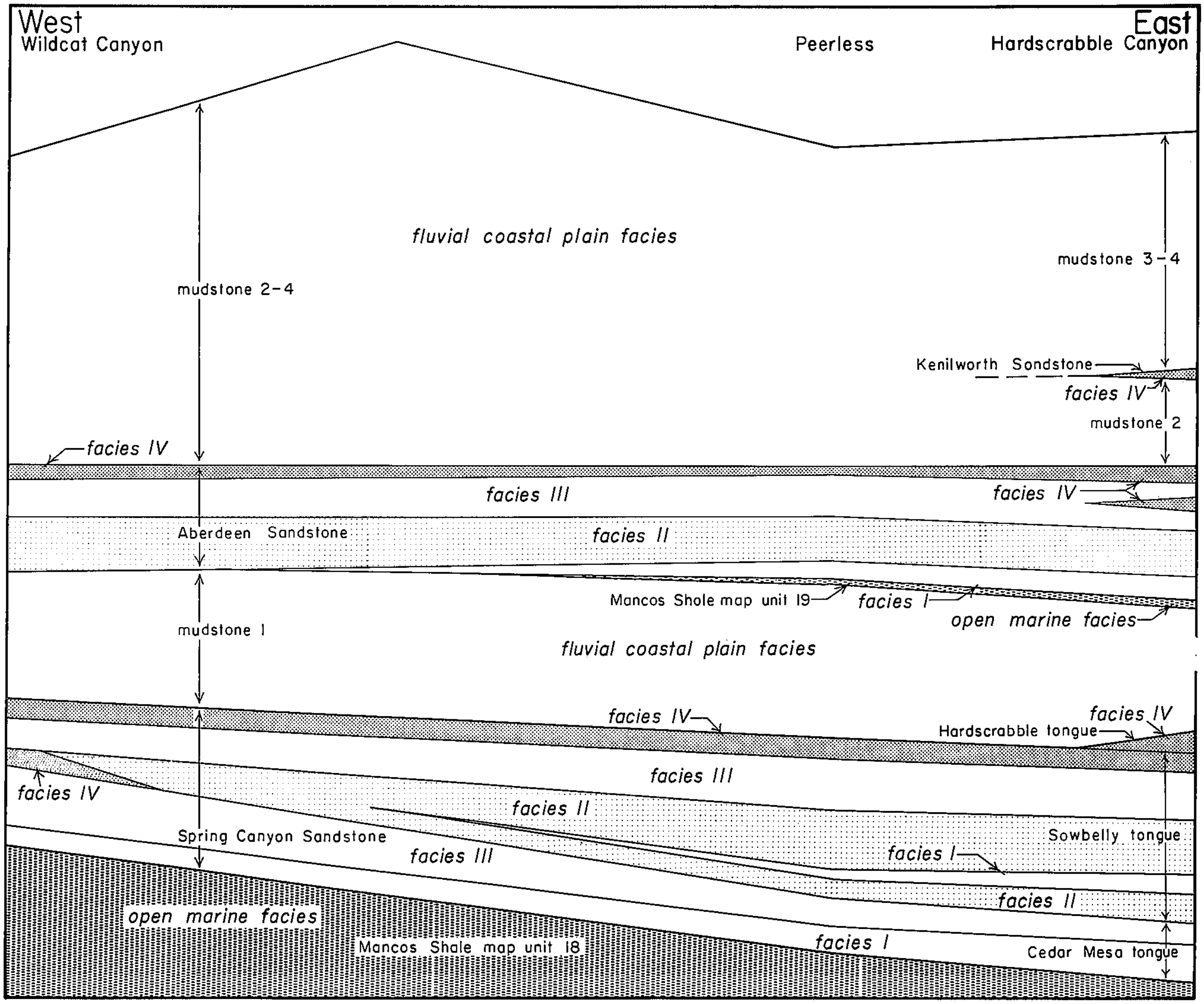

FIGURE 16.—*Panel diagram showing the relationships of facies I through IV in the Blackhawk Formation.*

Spring Canyon Sandstone Member. This member of the Blackhawk Formation is a laterally extensive unit mapped throughout the Wasatch Plateau and Book Cliffs. It is made up of many different sandstone tongues that combine to give the impression that the Spring Canyon is a single continuous sheet of sandstone. Three of these tongues are found within the Standardville Quadrangle and have been given informal names by local coal miners. These are the Cedar Mesa, Sowbelly, and Hardscrabble tongues (fig. 16) and are used informally here. The name Cedar Mesa, though previously used for a Permian sandstone in the Four Corners area, will be used for convenience in this paper. The lower two tongues are continuous and mappable throughout the quadrangle, while the upper Hardscrabble tongue pinches out westward within 1.5 km of the eastern border of the area. The overall thickness of the Spring Canyon Sandstone ranges from 35 m in Wildcat Canyon to 55 m in Hardscrabble Canyon. This eastward increase in thickness is attributed to an easterly thickening wedge of facies I and II between the Cedar Mesa and Sowbelly tongues.

The Cedar Mesa tongue is easily distinguished in the field by its massive nature and its characteristic medium yellow orange color. The tongue is composed of a basal facies I and an overlying facies III. At the extreme west edge of the quadrangle, the Cedar Mesa tongue develops a thin, light gray facies IV. In Wildcat Canyon the Cedar Mesa tongue has a total thickness of 19 m. To the east in Hardscrabble Canyon, beds of facies III thin to less than half their original thickness, and facies IV disappears entirely, but the facies I beds nearly double in thickness to give an overall thickness of 14 m for the tongue.

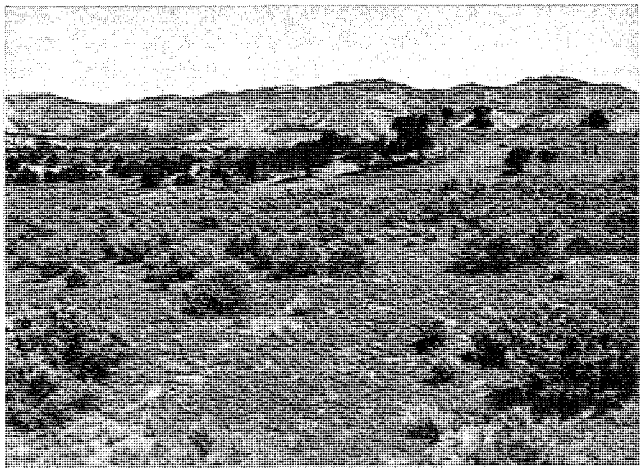

FIGURE 17.—*A view looking north onto the Book Cliffs escarpment (section 24, T. 13 S, R. 8 E; sections 19 and 20, T. 13 S, R. 9 E). The small hillock in the foreground (NE ¼, SE ¼, section 3, T. 14 S, R. 9 E) is held up by an igneous dike (Ti).*

The angle of cross-stratification within facies III is very shallow, and stratification is indistinct. The lower contact of the facies I sequence is gradational, while both the upper and lower contacts of the facies III bed are quite sharp. The fact that there is no facies II in this tongue may indicate that the rate of deposition was very rapid so that upper shore face sediments were laid down directly upon the transition zone between the lower shore face and open marine.

The Sowbelly tongue is the most prominent feature of the Spring Canyon Sandstone. In the west part of the area in Wildcat Canyon this tongue is represented by a sequence of facies III and IV that lies directly on the facies IV of the Cedar Mesa tongue. Farther to the east, in the canyon where the Peerless Mine is located, the Sowbelly tongue exhibits an ideal sequence of facies I through IV (fig. 18). Between this Peerless Mine section and Wildcat Canyon, facies I and II pinch out westward. In Hardscrabble Canyon, near the eastern edge of the quadrangle, the Sowbelly tongue is similar in most respects to the Peerless Mine section. Facies II through IV remain constant in thickness and character, but the thick basal facies I is replaced by an alternating sequence of facies I and II. The total thickness of the Sowbelly tongue decreases to the west from 39 to 13 m as facies I and II pinch out.

Distinct cross-stratification in facies I and III of the Sowbelly tongue at the Peerless section indicate a paleocurrent direction of northeast-southwest. This agrees with Balsley (1982, p. 61), who determined the bearing of the paleostrandline on the basis of measurements of trough cross-bed axes at 4,500 localities. The Spring Canyon A sub 3 coal, which lies directly on top of the Sowbelly tongue, pinches out to the southeast, which also indicates a northeast–southwest-trending coastline during deposition of the Spring Canyon Sandstone.

The Hardscrabble tongue in the study area is made up of facies III and IV only. At its thickest it is 4.5 m thick and rapidly pinches out to the northwest. It is traceable in Gentile Gulch and at the mouth of Hardscrabble Canyon. In Gentile Gulch the lower split of the Spring Canyon A sub 3 coal can be observed squeezed between sandstones of the Sowbelly and Hardscrabble tongues.

The Spring Canyon Sandstone represents deposition on a prograding wave-dominated delta and includes the entire sequence from prodelta and open-marine transition zone to the foreshore environments. Its several tongues indicate either shifting of the main distributary channel or minor periods of transgression and regression of the Mancos Sea, or both.

Mudstone 1 member. Mudstone 1 member is the slope-forming unit between the Spring Canyon and Aberdeen Sandstones. The sharp, basal contact is placed at the top

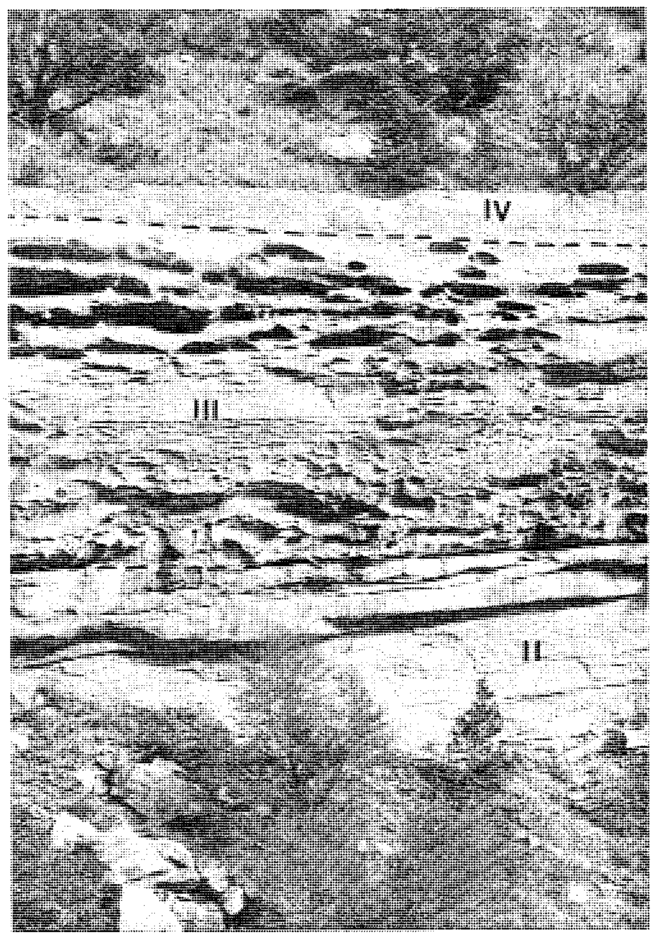

FIGURE 18.—*Facies II through IV in the Spring Canyon Sandstone on the east wall of Gilson Gulch in SE ¼, SE ¼, section 8, T. 13 S, R. 9 E.*

of the Sowbelly or Hardscrabble tongues of the Spring Canyon Sandstone. The upper contact is less distinct and is placed at the bottom of the cliff-forming Aberdeen Sandstone.

In the Standardville Quadrangle, mudstone 1 member ranges between 30 and 39 m thick. It pinches out eastward about 2.5 km into the Helper Quadrangle. As it pinches out, a tongue of Mancos Shale thickens between the Spring Canyon and Aberdeen Sandstones. About 5 km to the west, the overlying Aberdeen Sandstone pinches out, and mudstone 1 and 2–4 members unite to form the undifferentiated mudstone 1–4 map unit.

Mudstone 1 is composed of carbonaceous shale, siltstone, mudstone, fine- to medium-grained sandstone, and coal. Shales are dark gray to black and very organic. They are often associated with, and included within, major and minor coals. Siltstones and mudstones are also rich in plant debris. Well-preserved plant fossils of *Sequoia, Protophyllocladus, Araucaria, Metasequoia, Ficus,* and *Salix* are found within these deposits.

Sandstones are fine- to medium-grained and are very lenticular. Most are less than 3 m thick, but they may be as thick as 8 m. They make up a greater percentage of the unit in the western part of the quadrangle than in the east. These sandstones generally weather medium orange yellow. They exhibit oscillation and directional ripple marks and cross-laminations. The trace fossil *Pelecypodichnus*, which is a freshwater indicator (Balsley 1982, p. 177), is also found.

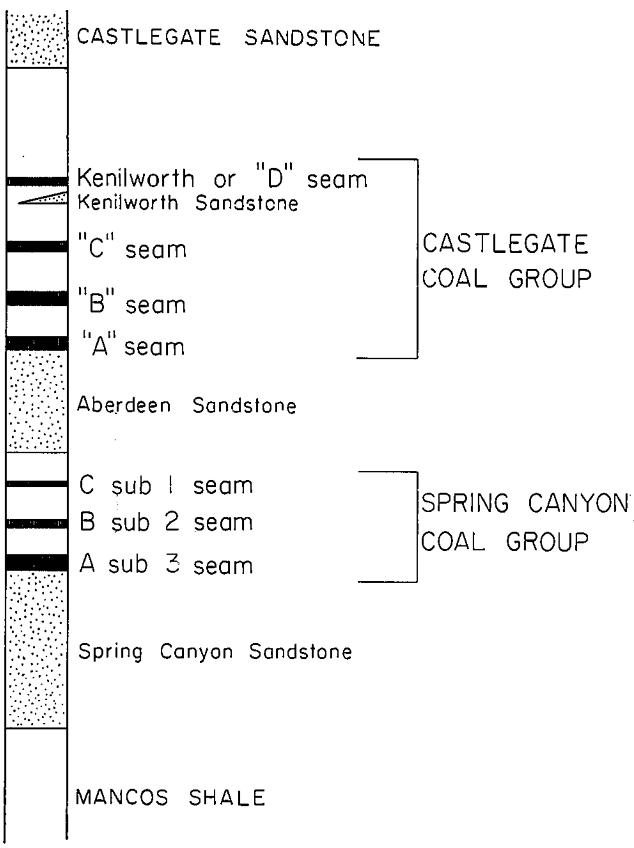

FIGURE 19.—*Position of minable coals in the Blackhawk Formation found within the Standardville Quadrangle and their relation to sandstone members of the Blackhawk Formation.*

These highly lenticular sandstones probably represent slightly to moderately sinuous stream channel-fill deposits. Balsley (1982, p. 177) indicated that point-bar deposits, reflecting deposition in highly sinuous streams, also occur in the fluvial coastal plain facies of the Blackhawk Formation. None of these kinds of deposits were recognized in sections of the mudstone members within the Standardville Quadrangle. Coals within mudstone 1 member constitute the Spring Canyon Coal Group (fig. 19).

This group contains three economic coals in the Standardville Quadrangle. These are the Spring Canyon A sub 3, B sub 2, and C sub 1 seams. Several other thinner and less continuous coals are also found in this unit.

The Spring Canyon A sub 3 coal (fig. 20) has a maximum thickness of 3.2 m in Sowbelly Gulch, but averages about 1.7 m throughout the quadrangle. An interval of 6 to 18 m separates the A sub 3 from the B sub 2 seams. The latter has a maximum thickness of 2.7 m in the subsurface in Robinson Gulch, but has an average thickness of only 1.2 m. The B sub 2 and C sub 1 coals are separated by 5 to 15 m of rock. The maximum thickness for the C sub 1 seam is 2.6, and it averages 1.1 m.

The coals in the Spring Canyon Coal Group probably developed in a delta plain environment. Because the Spring Canyon A sub 3 coal rests almost everywhere directly on top of the gently undulating surface of facies IV deposits of the Spring Canyon Sandstone, it is inferred that the coal-forming swamps were very closely associated with the beach-ridged strandline of a wave-dominated delta. No lagoon or other environment separated the barrier beach from the swamp since coals form directly on top of beach deposits. Root casts found near the top of facies IV rocks also support the conclusion that swampland vegetation was growing directly on top of the beach ridges. These delta plain coals are generally laterally extensive—both in length and width—and their geometries are considered to be similar to that of the supporting delta platform on which these swamps rested (Balsley 1982, p. 181–83).

Evidence from coalified and petrified wood and leaf impressions indicate that the coal-forming swamp community was dominated by *Sequoia, Brachyphyllum, Moriconia, Protophyllocladus,* and *Araucaria,* and the angiosperm *Rhamnites*. Undergrowth included the palm, *Geonomites*, and the ferns, *Cyathea* and *Onoclea* (Parker 1976). Parker (1976) suggested that angiosperms may

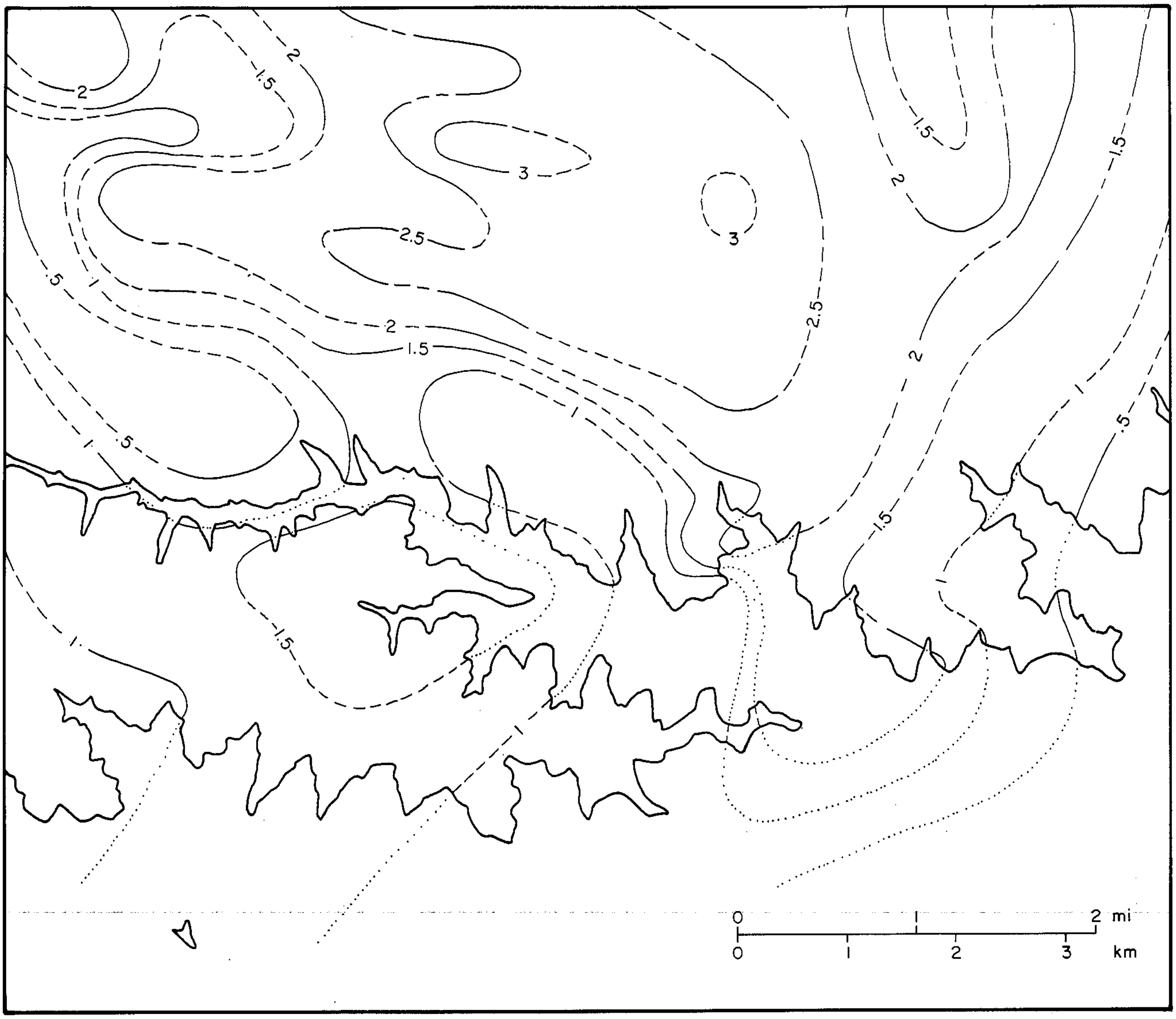

FIGURE 20.—*Coal isopach of the Spring Canyon A sub 3 seam. Thicknesses are in meters. The paleocoastline probably paralleled the 0.5 m contour in the southeast corner of the map. The heavy line expresses the A sub 3 coal outcrop.*

have played a greater role in these swamps than the megafossil evidence indicates, and indicated this may be due to the relative ease of preserving and identifying conifer foliage and the difficulty of identifying angiosperm leaves. Samples of the Spring Canyon A sub 3 and Castlegate "A" seams taken from the study area, and processed for palynomorphs by the author, indicate that angiosperms made up a far greater part of the swampland plant community than indicated by megafossil evidence. However, the possibility exists that much of the angiosperm pollen and leaves may have been swept into the swamps by feeder streams.

The isopach of the Spring Canyon A sub 3 coal (fig. 20) reveals a northwest–southeast-trending elongate area in which coal thicknesses are unexpectedly low—0.3 to 0.8 m compared to 1.2 to 2.7 m directly adjacent to it on either side. This may indicate erosion of already deposited coal by a minor distributary, or nondeposition due to a draping effect over some buried depositional feature. The isopach also shows that the coal thins toward the paleocoastline to the southwest.

Aberdeen Sandstone Member. The Aberdeen Sandstone Member of the Blackhawk Formation is thinner and less stratigraphically complex than the lower Spring Canyon Sandstone Member. It ranges in thickness from 22 to 32 m in the quadrangle and exhibits a gradual westward thinning. It pinches out rather abruptly about 5 km west of the quadrangle. At Alkali Creek, 20 km to the east in the Deadman Canyon Quadrangle, the Aberdeen Sandstone attains a thickness of 75 m and is made of up to six different tongues (Nethercott 1986). In the Standardville Quadrangle only one tongue is present.

The pattern of sedimentation of the Aberdeen Sandstone remains fairly constant throughout the quadrangle. In the canyon where the Peerless Mine is located a straightforward section of facies I–IV is present (fig. 16). Farther to the east, in Hardscrabble Canyon, facies I and IV thicken somewhat, and a thin sequence of facies IV beds splits the thick facies III. This probably represents the extreme western edge of a new tongue that develops farther to the east. To the west of the Peerless section the facies I beds pinch out, but the rest of the facies remain fairly constant in thickness.

Mudstone 2–4 members. Above the foreshore facies of the Aberdeen Sandstone and below the Castlegate Sandstone lies a thick section of carbonaceous shale, siltstone, mudstone, fine- to medium-grained sandstone, and coal. It is very similar to mudstone 1 member.

Each mudstone member represents a fluvial coastal plain facies that generally accumulated behind a prograding, wave-dominated barrier. Because of the transgressive-regressive nature of the Mancos Sea, these mudstone members are usually found sandwiched between two beach complexes. Mudstone 1 member occurs between the Spring Canyon and Aberdeen Sandstones; mudstone 2 member is only differentiated in the extreme eastern part of the quadrangle, where the Kenilworth Sandstone is present about 58 m above the Aberdeen Sandstone. The Sunnyside Sandstone divides the mudstone 3 member from the mudstone 4 member. However, the Sunnyside Sandstone pinches out westward 1.5 km east of the quadrangle. The Castlegate Sandstone is above mudstone 4.

Each mudstone member pinches out eastward between interdeltaic and prodelta deposits. Mudstone 2 member pinches out just east of Deadman Canyon, 13 km east of the Standardville Quadrangle, and mudstone 3 member pinches out near Rock Canyon, 29 km to the east. Mudstone 4 member is mappable as far as the Price River east of Woodside, about 77 km to the southeast (Balsley 1982, fig. 2).

Mudstone 2–4 member varies in thickness across the quadrangle from 224 to 335 m. There is a slight thickening trend to the east, but it undulates greatly across the quadrangle. This variation in thickness may be the result of postdepositional erosion, suggested by a possible disconformity between the Blackhawk Formation and the overlying Castlegate Sandstone in this area.

Lithologically, mudstone 2–4 member is similar to mudstone 1 member and, therefore, probably represents similar environments of deposition. A gradual increase in grain size occurs toward the top of the unit, and the top 30 to 50 m are dominantly fine- to coarse-grained, lenticular-bedded sandstone interbedded occasionally with gray shale and red-to-brown mudstone. This indicates that the delta plain had prograded far to the east and that the environment of deposition for the uppermost mudstone 2–4 member was inland from the coal-forming swamps.

Minable coals found in the mudstone 2–4 member in the Standardville Quadrangle are included in the Castlegate Coal Group (fig. 19). These are the Castlegate "A," "B," "C," and Kenilworth or Castlegate "D" seams. The Castlegate "A" seam lies directly upon the Aberdeen Sandstone (fig. 21) and has a maximum thickness of 4.6 m in the subsurface of Robinson Gulch. The isopach of the "A" seam exhibits a similar elongate area of abnormally thin coal thicknesses similar to what was seen in the Spring Canyon A sub 3 coal (fig. 20). However, the "A" seam area trends more east–west and is located about 2 km north of the A sub 3 area. This may indicate a migration of a distributary channel.

The Castlegate "B" coal (fig. 22) lies 12 to 24 m above the "A" seam and has a maximum thickness of 4.5 m in the subsurface near Ford Ridge. The "C" seam, which occurs 12 to 24 m above the "B" seam, has a maximum thickness of 2.5 m near the northern edge of the quadrangle in the subsurface. It is only locally minable. The Kenilworth or Castlegate "D" seam is separated from the "C" seam by 17 to 30 m of rock and has a maximum thickness of 4.0 m. It has been mined extensively in the Standardville Quadrangle.

The Kenilworth Sandstone crops out, and was mapped, in the extreme eastern part of the quadrangle. It lies about 58 m above the Aberdeen Sandstone. Several other discontinuous sandstones also occur near this level in the eastern half of the quadrangle and may be related to deposition of the Kenilworth Sandstone. However, no direct correlation can be made. Russon (1987) described the unit in detail in the Helper Quadrangle immediately to the east, where it crops out continuously throughout the area.

Castlegate Sandstone

The Castlegate Sandstone was originally designated the lower, non-coal-bearing member of the Price River Formation (Spieker and Reeside 1925), but has since been elevated to formation rank by Fisher, Erdmann, and Reeside (1960) on the basis of lithology and areal extent. The type section of the Castlegate Sandstone is located within the Standardville Quadrangle at The Castlegate

FIGURE 21.—*A 3.7 m thick outcrop of the Castlegate "A" seam in Gilson Gulch. It is resting directly on top of the Aberdeen Sandstone.*

(SW 1/4, SE 1/4, section 26, T. 12 S, R. 9 E) in Price River Canyon. There, and throughout the quadrangle, it forms a prominent cliff between the slope- and ledge-forming Blackhawk and Price River Formations (fig. 23). Spieker and Reeside (1925, p. 446) dated the Castlegate Sandstone as late Montanan.

The Castlegate Sandstone in the Standardville Quadrangle is a light gray to medium orange gray, cross-bedded, fine- to very coarse-grained quartzose sandstone. Other clastic material includes chert, kaolinized feldspar, organic debris, and mud rip-up clasts. Lenses of horizontally laminated, shaly siltstone, fine-grained sandstone, and rare thin coals are interbedded within the cross-bedded sandstones in some horizons. These siltstone lenses are up to 3 m thick and 90 m wide, but are generally less than 1 m thick and 20 m wide and are characteristically a medium gray to medium red brown color due to their high organic and iron oxide content.

Grain size generally decreases upward within the formation, but little lateral variation is evident across the quadrangle. The Castlegate Sandstone is medium- to massive-bedded, and bedding is very lenticular. Cross-bedding is the dominant sedimentary structure with bed sets ranging from 15 to 60 cm thick. Current direction, based on these cross-laminations, is generally to the east and northeast. Bioturbation is only rarely seen in the Castlegate Sandstone; however, root casts are sometimes recognizable in tops of sandstone beds and in more shaly units.

The lower contact of the Castlegate Sandstone was mapped at the base of the sandstone ledge and top of slope-forming mudstone member 2–4 of the Blackhawk Formation. Occasionally, however, the Castlegate Sandstone lies directly upon a thick, resistant, channel-fill sandstone of the Blackhawk Formation. Where this occurs, color differences between the sandstones and lateral relationships were used to differentiate the two formations. The upper contact of the Castlegate Sandstone with the Price River Formation is conformable and gradational. It was mapped at the bottom of the first slope-forming unit above the massive sandstone of the Castlegate Sandstone. It is generally sharp and easily discern-

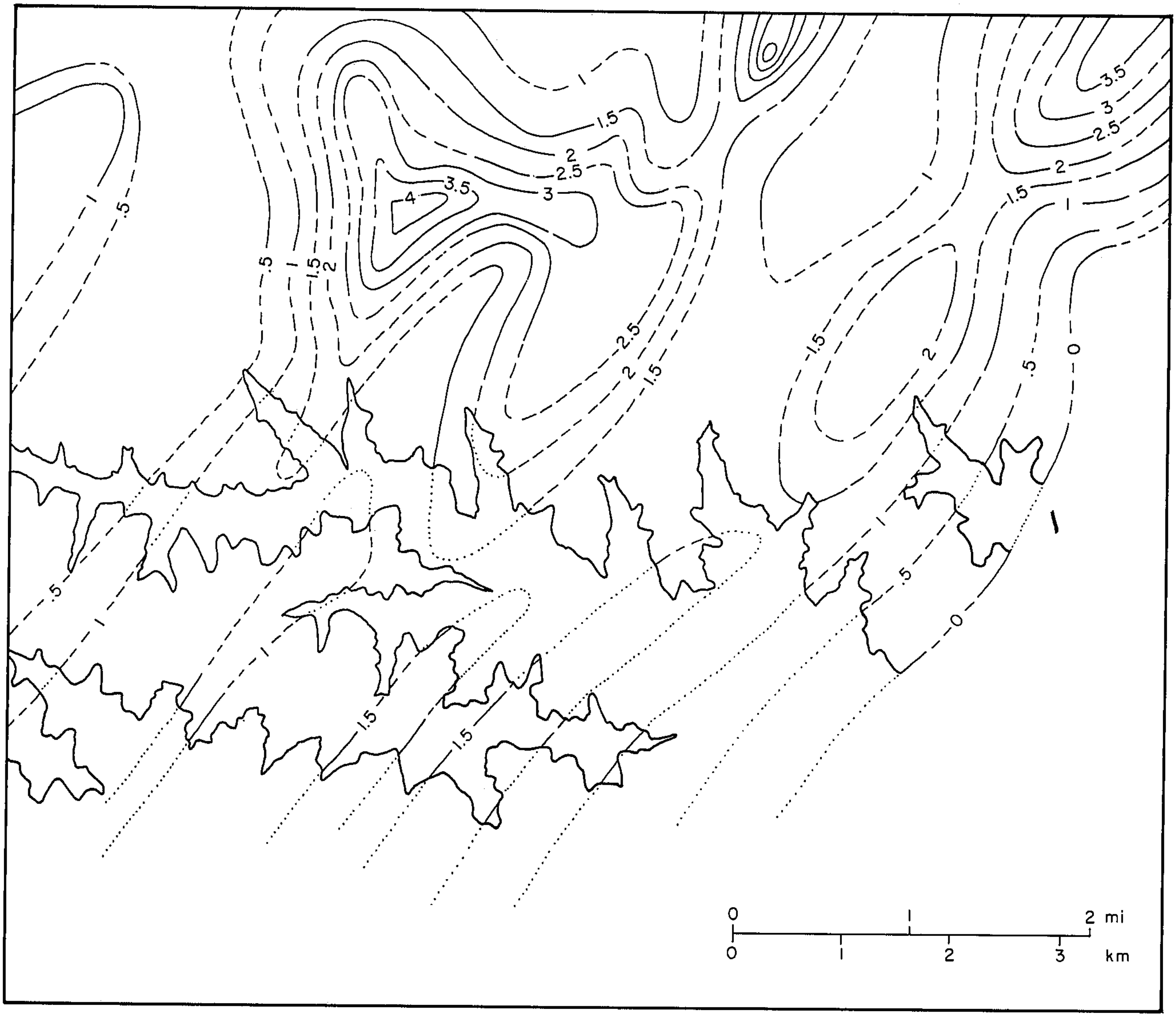

FIGURE 22.—*Coal isopach of the Castlegate "B" seam. Thicknesses are in meters, and the heavy line expresses the outcrop of the coal.*

ible, but becomes less so toward the west where rocks are less well exposed.

Spieker and Reeside (1925, p. 445–46) and Young (1955) have suggested that the Castlegate Sandstone lies disconformably upon the Blackhawk Formation in the Wasatch Plateau and westernmost Book Cliffs. Two problems arise within the Standardville Quadrangle, and in most other areas, that make this unconformity difficult to substantiate. First, the contact is almost always covered. Second, where it is exposed, the extremely lenticular nature of the beds, both above and below the contact, make angular relationships between the two almost impossible to define.

Regionally, the Castlegate Sandstone is a wedge-shaped sedimentary body that thins eastward from 183+ m in the Wasatch Plateau to virtually nothing at the Utah-Colorado border. Thicknesses of this formation within the quadrangle range between 73 and 88 m, but no substantial overall thinning to the east is evident.

Within the Standardville Quadrangle the Castlegate Sandstone represents deposition within a fluvial system. Lenticular bedding within this formation reflects numerous, low sinuosity streams typical of the coalescing or braided stream model (Van De Graaff 1972). Rare lenses of organic-rich, fine-grained sediment are probably flood-plain or fine-grained channel-fill deposits. To the east of

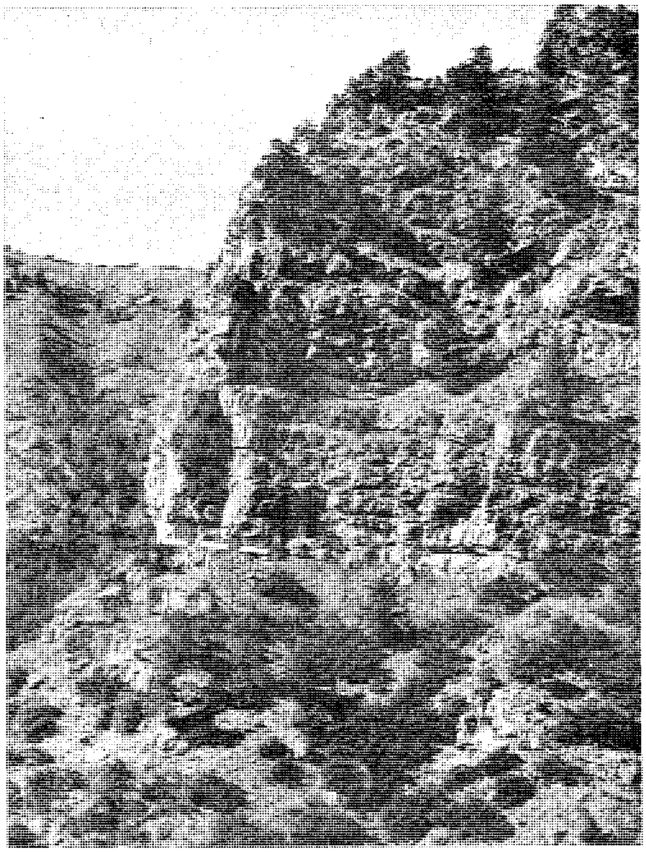

FIGURE 23.—*Castlegate Sandstone (Kc), and its lower contact with the Blackhawk Formation (Kb), looking east in Bear Canyon (NW 1/4, SE 1/4, section 34, T. 12 S, R. 9 E).*

the quadrangle the Castlegate Sandstone grades from fluvial facies into a shoreline facies, a delta front facies, and finally into a Mancos Shale shallow marine facies at about the Utah-Colorado border. To the north and west it becomes a red-bed conglomeratic facies and is mapped together with the Price River Formation or undifferentiated Price River-North Horn Formations (Van De Graaff 1972).

Price River Formation

The Price River Formation was named by Spieker and Reeside (1925) for outcrops in Price River Canyon, immediately north of the Standardville Quadrangle. The formation is similar, in most respects, to the underlying Castlegate Sandstone except that it has numerous intervals of fine-grained clastic sediments. The repetitive slope-ledge outcrop above the cliff-forming Castlegate Sandstone makes the Price River Formation easily identified in the field. Abbott and Liscomb (1956, p. 122) and Cobban and Reeside (1952) stated that the Price River Formation is of Campanian to Maestrichtian age.

Slope-forming units are interbedded light gray, noncalcareous mudstone, silty shale, and thin beds of fine-grained sandstone. Coalified plant debris is abundant in these units, and very thin, lenticular coal beds are sometimes present. Most sedimentary structures have been obliterated by bioturbation, but where observable, horizontal lamination is the most prominent structure. Tops of thin fine-grained sandstone beds are often current rippled, but no dominant direction of current movement is evident. The lower contact of slope-forming units is often gradational, but the upper contact is usually sharp. These units make up between 66% and 78% of the Price River Formation in the Standardville Quadrangle.

Ledge-forming units are generally light colored and are composed of fine- to coarse-grained quartzose sandstone. Cross-stratification is prominent, and bedding is highly lenticular. Wedge-shaped, sandstone-pebble conglomerate lenses, up to 0.5 m thick, are often exposed near the base of these sandstone units. Most of these sandstone ledges cannot be traced with confidence more than about 3 km; however, several prominent ledges are traceable nearly the entire width of the quadrangle.

The upper contact of the Price Rive Formation with the North Horn Formation has been defined in several different ways. Spieker and Reeside (1925, p. 445) put the top of the Price River Formation at the appearance of local limestone pebble conglomerates. Clark (1928, p. 21) suggested that an unconformity exists between the Price River and North Horn Formations and defined the contact on the basis of a basal conglomerate. Spieker (1946) placed the contact at the level of greatest lithologic change while Young (1957, p. 187) put it at the base of the first recognizable red bed. No traceable pebble conglomerates were located within the area, but in the northwest corner of the quadrangle red beds crop out just above the highest major sandstone. This was used as the contact because it satisfied the conditions for both Spieker's (1946) and Young's (1957) definition of the contact.

At the type section, the Price River Formation measures about 350 m thick. Westward through the quadrangle the formation thins to about half that thickness. The same amplitude of thinning occurs east of Price River Canyon in the Helper and Deadman Canyon Quadrangles (Nethercott 1986, Russon 1987). East and south of Deadman Canyon Quadrangle, the formation again thickens so that near Thompson, Utah, it measures 650 m (Howard 1966b). Local syndepositional warping due to early uplift and deformation associated with the San Rafael Swell and pre-Tertiary erosion are possible explanations for the regional variations in thickness (Howard 1966b, p. 15).

The Price River Formation represents fluvial and associated floodplain environments. Major lenticular-bedded, cross-laminated sandstone units probably represent areally extensive braided stream environments, whereas minor sandstones associated with the mudstone facies are probably local channel fill or overbank flood deposits (Nethercott 1986). On the whole, the Price River Formation was deposited in an environment very similar to that of the Castlegate Sandstone except that floodplain rather than braided stream deposition dominated the system.

North Horn Formation

The youngest preserved consolidated sedimentary unit in the Standardville Quadrangle is the North Horn Formation. It was named by Clark (1928) for exposures on North Horn Mountain in the Wasatch Plateau, and lies gradationally or locally unconformably on the Price River Formation. Vertebrate fossil evidence indicates that the North Horn Formation straddles the Cretaceous-Paleocene boundary (Gilmore 1946, Robison 1986).

In Price River Canyon, the North Horn Formation measures about 670 m thick, but thins to 420 m near the western edge of the quadrangle. However, only the lowermost 300 m are exposed within the boundaries of the Standardville Quadrangle, and it's likely only Cretaceous beds are represented in this lower section. East of the quadrangle the formation thins to about 310 m within the bordering Helper Quadrangle (Russon 1987) and gradually thins to only 61 m thick at the eastern end of the Book Cliffs (Young 1955). The thinning and thickening pattern of this formation is quite similar to that of the Price River Formation, and, therefore, probably has similar origins.

The North Horn Formation in the area of the Standardville Quadrangle forms a poorly exposed ledgy slope. It consists of variegated shale, mudstone, conglomerate, freshwater limestone, and thin, lenticular sandstone. Shales and mudstones range from dark brown and reddish brown to dark gray green. Sandstones are predominantly quartzose with limonitic cement and are generally crossbedded. Clasts of the conglomerates are mostly clay lumps, but chert pebbles were also observed. They range in size from 0.5 to 3 cm in a matrix of medium to very coarse quartz sand. Limestone units occur primarily near the top of the formation and form resistant ledges that are capped by the dip-slope-forming beds of the Flagstaff Formation. These limestone units have a light yellow gray color when fresh, but weather light gray. They are thin to medium bedded, contain freshwater bivalve and gastropod fragments, and are silty.

Environments of deposition of the North Horn Formation are mixed lacustrine and fluvial systems, with lacustrine deposition becoming dominant near the top of the formation based on the increased percentage of limestone units. Deposition probably took place on an areally extensive, low-lying floodplain adjacent to a large inland lake or lake system. This is supported by the conformable and gradational contact with the overlying, dominantly freshwater limestones of the Flagstaff Formation. Coarse-grained sandstones and conglomerates of the North Horn Formation probably represent meandering stream deposition in contrast to the braided stream deposits of the underlying Castlegate Sandstone and Price River Formation. This suggests a possible lessening of the regional gradient from Price River to North Horn time.

TERTIARY SYSTEM

Igneous Dike

The only igneous unit cropping out within the Standardville Quadrangle is a single dike located at NE 1/4, SW 1/4, section 3, T. 14 S, R. 9 E (figs. 16 and 24). It is somewhat resistant and holds up a small linear hillock about one-fourth mile long within the Mancos Shale. The dike strikes N. 64° W. and appears to be very nearly vertical. It is 1.25 m thick, and the adjacent Mancos Shale has been baked to an argillite up to 1 m away from the intrusion. It is a mafic dike rock with phenocrysts of augite and altered olivine, and has a groundmass rich in augite and magnetite (Myron G. Best oral communication 1984). Two other dikes, which do not crop out at the surface, were located on maps of old mine workings at SW 1/4, NE 1/4, section 12, T. 13 S, R. 8 E. These two dikes are mapped as parallel to each other about 70 m apart for about one-fourth mile and strike N. 87° W. Nothing is known about the composition of these dikes.

Dikes in the Standardville area belong to a larger dike system developed in the Wasatch Plateau. Thomas (1976) grouped these dikes into three compositions: biotite orthoclase pyroxene lamprophyre, diabase, and an acidic sandstonelike intrusion. The dike exposed within the Standardville Quadrangle seems to represent a compositionally new dike rock in this area. Further work will be required to establish its relationship with other dikes in the Wasatch Plateau. The northwest–southeast strike of these dikes is subparallel to a fault system mapped in the Jump Creek area to the west of the area by Hansen (in press). He has suggested that this fault system may have partially controlled emplacement of the dikes. The middle to late Tertiary age of the dikes is based on regional relationships (Thomas 1976).

QUATERNARY SYSTEM

Quaternary deposits in the Standardville Quadrangle of Holocene and Pleistocene (?) age are composed chiefly of unconsolidated, silt- to boulder-sized debris that is generally unstratified, or that may show a crude stratification. These deposits include pediment gravel, Mancos Shale lag, older alluvium and younger alluvium, and are primarily restricted to the southern half of the quadrangle.

FIGURE 24.—*An excavation in the igneous dike (NE ¼, SW ¼, section 3, T. 14 S, R. 9 E) exposed in shale unit 3–6 of the Mancos Shale. The darker colored dike is 1.25 m wide.*

Pediment Gravel

Pediment gravel consists of sand- to boulder-sized debris derived from the fine- to very coarse-grained sandstones of the Star Point and Blackhawk Formations that make up the Book Cliffs escarpment. The largest clast observed in these deposits measures 5 by 2.5 m, but average coarsest material is generally about 0.5 m in diameter. The specific origin of many of these larger boulders can be determined by characteristic color, grain size, sedimentary structures, and trace fossils.

Thicknesses of these gravels range from 2 to 10 m. These deposits are located at the base of the Book Cliffs and form isolated, flat-topped terraces that slope gently to the south. Preserved remnants of these gravel layers cover areas from about 500 square m to 0.6 square km, but areas much larger than this may be covered by Mancos Shale lag deposits. Areas blanketed by pediment gravel increase in size east of the quadrangle, where individual remnants may be as large as 5 square km.

Nethercott (1986) observed five levels of pediment development in the area of Deadman Canyon, 15 km to the east. Within the Standardville Quadrangle, however, only two distinctly different ancient pediment levels were recognized. Correlation of the various levels of pediment development within the quadrangle is difficult at best, and Carter (1977) stated that correlation of these levels from one area to another along the Book Cliffs cannot be accomplished with any degree of confidence. Explanations for development of the different pediment levels include lateral migration and planation of streams unable to downcut because of heavy sediment load (Gilbert 1877) and stream downcutting due to climatic changes, tectonic uplift, or escarpment retreat (Rich 1935). Carter (1977) proposed an alternative model involving repeated stream capture and aggradation of the bedrock surface by debris floods and suggested that such a process was independent of climatic changes, tectonics, or escarpment retreat.

Mancos Shale Lag

Deposits of unconsolidated silt and fine-grained sand blanket much of the quadrangle south of the Book Cliffs escarpment. These lag deposits are produced by the winnowing of fine material away from weathered silty Mancos Shale. Transportation of the silt and sand may or may not occur. In sections 33–35 of T. 13 S, R. 9 E, and sections 2–5 and 8–10 of T. 14 S, R. 9 E, these deposits appear to have been produced by in situ weathering of the Mancos Shale for they lie directly upon the parent formation. However, to the northeast, in sections 29–32 of T. 13 S, R. 9 E, they lie on pediment gravel. Transportation of these latter sediments was probably by slope wash. In some instances crude horizontal- and cross-laminations can be observed. These Mancos Shale lag deposits probably are no thicker than 2 m, and in most cases are less than 1 m thick.

Older Alluvium

Deposits mapped as older alluvium consist of poorly sorted, silt- to boulder-sized fluvial sediments that have been incised by recent stream erosion (fig. 10). The clasts are generally well rounded and subspherical and were derived from resistant formations of the Book Cliffs and Wasatch Plateau. These alluvial deposits may exhibit some lenticular channel bedding. Streams have cut 2 to 6 m into these deposits, leaving small flat-topped remnants and terraces on the sides of the valleys. These older alluvial deposits have been recognized in the southwest corner of the quadrangle in upper parts of Garley Canyon and North Fork Gordon Creek.

Younger Alluvium

Younger alluvial deposits are similar in most respects to older alluvium but have not been incised. These deposits are restricted to the major drainages in the area. Thicknesses are probably 10 m or less, and thickest deposits occur in Price River Canyon and at the mouth of Spring Canyon.

STRUCTURAL GEOLOGY

Geologic structures of the Standardville 7½′ Quadrangle are dominated by homoclinal dips to the north associated with the San Rafael Swell (fig. 25). Substantial thickness variation in the Price River Formation and the overlying North Horn Formation in the Standardville Quadrangle and areas to the east (fig. 26) indicates that syndepositional warping associated with the uplift of the San Rafael Swell began as early as Price River time.

Rocks in the northeast part of the area (T. 12 S, R. 9 E, and T. 13 S, R. 9 E) strike N. 85° W. and dip northward at about 6 degrees. To the northwest (T. 12 S, R. 8 E, and T. 13 S, R. 8 E) the beds bend to form a broad shallow anticline at the edge of the quadrangle and have a general strike of N. 58° W and dip 7 to 12 degrees to the northeast. The broad syncline to the east of this is the northern extension of the Straight Canyon Syncline (Walton 1955, p. 347). In the southern part of the quadrangle, rocks strike uniformly N. 80° W. and dip northward at 4 to 6 degrees. A shallow anticline and syncline occur in the area of Hardscrabble Canyon.

A normal fault with maximum displacement of 35 m and a trend of N. 10° W. was mapped in the extreme northwest corner of the quadrangle. This is the southern extension of the Forge Mountain Fault (Walton 1955, Moussa 1965). Several other normal faults within the quadrangle have displacements of between 2 and 6 m. Maps of old coal mine workings show several faults of the same magnitude, but these faults are not observable at the surface.

Only a few kilometers west of the quadrangle, the geology becomes complexly faulted. Hansen (in press) has mapped two major systems of faults in the area of the Jump Creek 7½′ Quadrangle, adjacent on the west. The two systems have general trends of N. 5° E. and N. 55° W. He suggested that the faulting may be related to movement and collapse of evaporites within the Jurassic Carmel Formation. Isopachs of these evaporites (Moulton 1976, p. 225) show an eastward thinning and pinch out of the salt not far to the west of the Jump Creek Quadrangle. This supports the conclusion that the faulting is related to evaporite movement and solution, and explains the abrupt contrast in the structure of the two quadrangles. Apparently no major evaporite deposits occur in the subsurface of the Standardville Quadrangles.

ECONOMIC GEOLOGY

Coal is by far the most obvious economic resource in the Standardville Quadrangle. It has been mined in this area since 1896, and two active mines are currently in operation. Seven coal seams of sufficient thickness for mining are located in the quadrangle. Although no oil or gas has been recovered from the study area, potential for these resources has been largely overshadowed by coal resources. Large deposits of unconsolidated silt, sand, and gravel occur in the southern half of the quadrangle and could be utilized by the construction and building industries. Water, essential to most of these industries, is probably a restrictive factor in future development of these resources in the semiarid Standardville Quadrangle.

COAL

As early as 1870, attempts were made to haul coal by wagon from Carbon County to Salt Lake City. However, major mining operations were not begun until 1882 when the Denver and Rio Grande Western Railroad was completed between Price and Salt Lake City. In 1912 the first mine located in the Standardville Quadrangle opened in Hardscrabble Canyon. It is estimated that during World

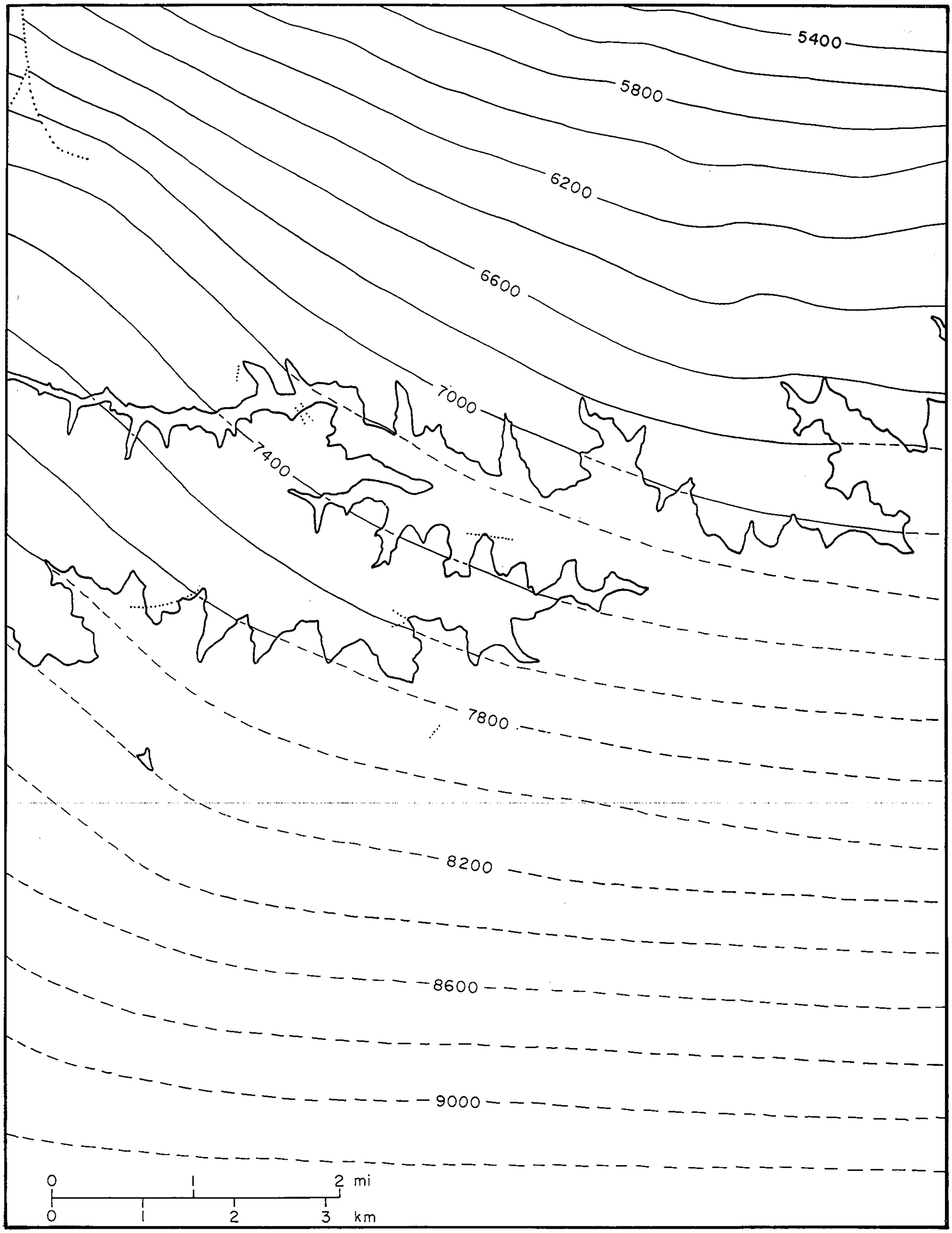

FIGURE 25.—*Structural contour map of the Standardville Quadrangle. Datum is the top of the Spring Canyon Sandstone, the outcrop of which is shown as the heavy, continuous line. Dotted lines are faults.*

War II, when demand for coal was very high, at least 8,000 tons of coal were mined each day in the Spring Canyon area (Robinson 1973). Today, only two mines, the Price River No. 5 Mine in Sowbelly Gulch and Price River No. 3 Mine in Hardscrabble Canyon, are in operation.

Within the Standardville Quadrangle, seven coal seams in the Blackhawk Formation are potentially minable (fig. 19). The Spring Canyon Coal Group, located in the mudstone 1 member, consists of the Spring Canyon A sub 3, B sub 2, and C sub 1 coals. Above this, and separated from the Spring Canyon Coal Group by the Aberdeen Sandstone, is the Castlegate Coal Group. It is made up of the Castlegate "A," "B," "C," and the Kenilworth or Castlegate "D" seams. To the east, the Kenilworth or Castlegate "D" seam is separated from the Castlegate Coal Group by the Kenilworth Sandstone and is not included in this coal group. Many other thinner and very lenticular coals also occur in the area—especially within mudstone 2–4 member. These coals, however, are not economically minable at the present, but may be exploited in the future as targets for in situ coal gasification. Coal thicknesses for isopachs and reserve estimates are based upon 47 drill logs provided by Price River Coal Company and 280 outcrop measurements (Doelling 1972, p. 342–47).

Over 500 coal samples from the Standardville Quadrangle were analyzed by Doelling (1972, p. 348) for moisture, volatile matter, fixed carbon, ash, sulfur, and BTU per pound, and average percentages were calculated for each component. These samples were taken from several mines at different localities; therefore, it is impossible to make estimates for specific coal seams. In general, coals of the Standardville Quadrangle are classified as high-volatile B bituminous based on these averages.

Doelling (1972, p. 351) estimated the total original coal reserves for all coal seams over 1.2 m (4 ft) in the Standardville Quadrangle and the southern third of the Kyune

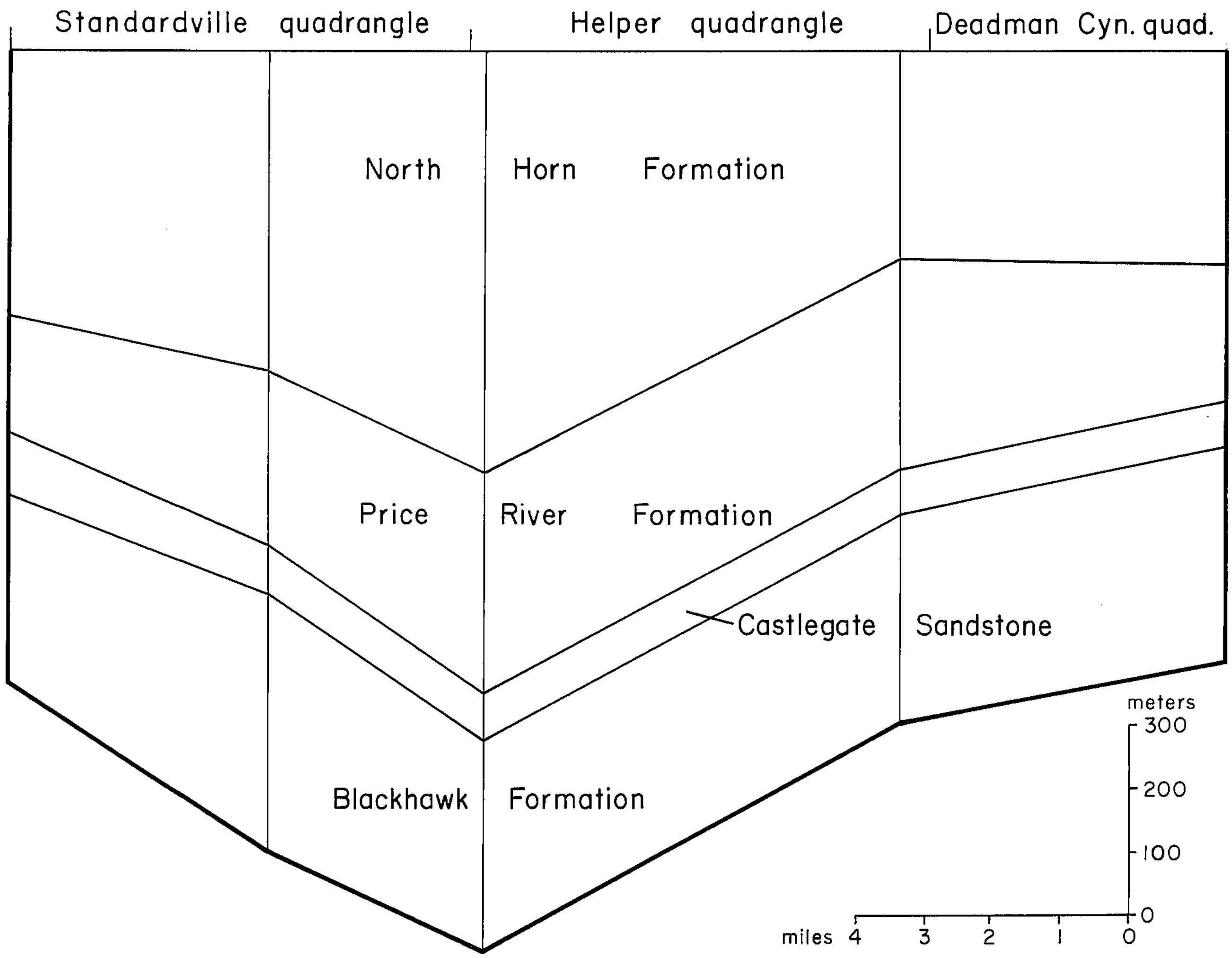

FIGURE 26.—*Panel diagram illustrating thickness of the Blackhawk through North Horn Formations from the west edge of the Standardville Quadrangle to the central part of the Deadman Canyon Quadrangle in the east.*

Quadrangle to the north at 567 million short tons. Of that, 53 million tons were mined between 1896 and 1969 at about 50% recovery. Therefore, an estimated 454 million tons of coal are yet in the area.

Price River Coal Company set estimates of remaining minable coal between 1.5 and 3.8 m (5 and 12 ft) at 243 million tons based on company data (Laine Adair personal communication 1984).

Analysis of isopachs of the seven minable coals developed by the author of this study may yield different figures than those of Doelling (1972) or Price River Coal Company. This is due to differences in interpretation of coal seam geometries and, in a few instances, in seam correlation.

Spring Canyon A Sub 3 Coal Seam

The Spring Canyon A sub 3 coal (fig. 20) lies directly on top of the Spring Canyon Sandstone and can be traced the entire width of the quadrangle. Maximum thickness for this seam is 3.2 m (10.5 ft) in the subsurface at Sowbelly Gulch, but it averages about 1.7 m (5.5 ft) thick over the quadrangle. The seam is lens-shaped—pinching out to the northwest and southeast. The Hardscrabble tongue of the Spring Canyon Sandstone splits the A sub 3 coal. The upper split continues to the east 1 to 2 km while the lower split pinches out abruptly.

The Spring Canyon A sub 3 seam has been correlated with the Hiawatha seam to the west and southwest. While these two seams no doubt belong to the same coal group, they are probably not the same coal seam. More likely, the Hiawatha coal rests on a lower tongue of the Spring Canyon Sandstone. Flores and others (1984) illustrated this shingling in the Hiawatha coal in the area of Ferron Canyon to the southwest.

This coal has been mined extensively in the area of Sowbelly Gulch and is currently being worked in Hardscrabble Canyon. Approximately 35% of the minable area within the quadrangle has been mined out. Interburden between the A sub 3 and the B sub 2 varies between 6 and 18 m (20 and 60 ft) and averages about 12 m (40 ft). Overburden reaches 914 m (3000 ft) at only one locality high on Ford Ridge and averages about half this. However, mining of this seam has taken much of the coal with less than 457 m (1500 ft) of overburden.

Spring Canyon B Sub 2 Coal Seam

The middle coal seam of the Spring Canyon Coal Group lies 7 to 21 m (25 to 70 ft) above the Spring Canyon Sandstone. The outcrop of this coal is continuous across the quadrangle. Maximum thickness is 2.7 m (9.0 ft) in the subsurface at Robinson Gulch, but except for this one locality it rarely exceeds 1.7 m (5.5 ft). The seam averages about 1.2 m (4.0 ft) thick. The coal bed is lenticular and has a north-south trend to this lenticularity, which appears to be subparallel to the paleostrandline. The seam tends to be more consistently minable in the northwest and north-central part of the quadrangle.

The B sub 2 coal has been mined fairly regularly up to 1.5 km from the outcrop on both the north and south side of Spring Canyon. About 70% of the minable area in the quadrangle for this coal has already mined; therefore, future major production in this seam is unlikely. Interburden between the Spring Canyon B sub 2 and C sub 1 coals ranges from 5 to 15 m (17 to 50 ft). In the northeast corner of the quadrangle, the C sub 1 coal is not present, and the interburden between the Spring Canyon B sub 2 and the Castlegate "A" seam ranges from 43 to 67 m (140 to 220 ft). Overburden does not vary significantly from that of the Spring Canyon A sub 3 coal seam.

Spring Canyon C Sub 1 Coal Seam

The C sub 1 coal seam lies 15 to 30 m (50 to 100 ft) above the Spring Canyon Sandstone. The outcrop of this coal is continuous throughout the western part of the quadrangle, but the bed pinches out about 1 km east of Sowbelly Gulch. Maximum thickness is 2.6 m (8.4 ft), measured in the outcrop in Sowbelly Gulch. Average thickness, however, is about 1.1 m (3.5 ft). This seam, as with the B sub 2 seam, has a lenticularity that parallels the ancient coastline. However, the C sub 1 coal seems to exhibit a general increase in thickness to the northwest.

Doelling (1972, p. 350) stated that the Spring Canyon C sub 1 coal was mined at the Spring Canyon No. 2½ Mine in Sowbelly Gulch and at the Liberty No. 4 Mine on the south side of Spring Canyon. The extent of mining in this seam is unknown. Interburden between the Spring Canyon C sub 1 and Castlegate "A" seams ranges from 30 m (100 ft) in the northwestern corner of the quadrangle to 49 m (160 ft) to the east. Again, overburden for this coal seam does not vary greatly from that of the A sub 3 seam.

Castlegate "A" Coal Seam

The Castlegate "A" coal lies directly upon or within 1.5 m (5 ft) of the Aberdeen Sandstone (fig. 21) and is the lowest coal in the Castlegate Coal Group. Outcrop of the coal is continuous in the eastern part of the quadrangle, but it is inconsistently present in the west. Maximum thicknesses of the "A" seam include a thickness of 4.6 m (15.2 ft) in the subsurface at Robinson Gulch and a thickness of 4.3 m (14 ft) in the subsurface in the northwestern corner of the area. The coal averages about 2.1 m (7.0 ft) for the quadrangle. The Castlegate "A" seam remains minable in the Helper Quadrangle to the east, where it attains a thickness of 5.8 m (19.1 ft). It has also been correlated with a coal seam extending into the Wasatch Coal Field (AAA Engineering 1979, p. 9).

Subsurface data indicate that the "A" seam has two distinctly separate areas of minable coal north of Spring Canyon. An east–west-trending bed of coals 1 km wide and between 0.3 and 0.9 m (1.0 and 3.0 ft) in thickness runs between these two areas. About 70% of the southern area has already been worked, but the area to the north has not yet been developed.

Interburden between the Castlegate "A" and Castlegate "B" seams ranges from 12 to 24 m (40 to 80 ft) and averages about 18 m (60 ft). Overburden reaches a maximum of 853 m (2800 ft), and most of the undeveloped area lies under 458 to 853 m (1500 to 2800 ft) of overburden.

Castlegate "B" Coal Seam

The Castlegate "B" seam (fig. 22) lies 11 to 20 m (35 to 65 ft) above the Aberdeen Sandstone. It crops out continuously throughout the Book Cliffs escarpment and Spring Canyon but pinches out to the southwest at the mouth of Spring Canyon and about 1.5 km up Hardscrabble Canyon. In the subsurface near Ford Ridge the "B" seam reaches a maximum thickness of 4.5 m (14.6 ft). It averages about 1.7 m (5.5 ft) thick throughout the area. The "B" seam has been mined in Sowbelly Gulch and Hardscrabble Canyon, but approximately only 15% of the area of minable thickness has been worked. This coal, therefore, has much potential for future development. Interburden between the Castlegate "B" and "C" seams in the northeastern part of the quadrangle ranges from 12 to 24 m (40 to 80 ft). In the north central part of the quadrangle the Castlegate "C" seam is not present, so 34 to 44 m (110 to 145 ft) of interburden separates the "B" and Kenilworth or "D" seam. Overburden is essentially the same for the "B" seam as for the "A" seam.

Castlegate "C" Coal Seam

The Castlegate "C" seam, also known as the "C west" seam, occurs 43 to 58 m (140 to 190 ft) above the Aberdeen Sandstone. Its outcrop is irregular, and only a few small, isolated areas of coal with minable thickness occur in the quadrangle. At the north edge of the quadrangle, a thickness of 2.5 m (8.2 ft) was recorded in the subsurface.

An area of this coal has been mined north of Hardscrabble Canyon, and to the east in the Helper Quadrangle, the Castlegate "C east" coal seam reaches minable thickness. Interburden between the Castlegate "C" and "D" seams ranges from 17 to 30 m (55 to 100 ft). Areas of minable coal thickness have 152 to 610 m (500 to 2000 ft) of overburden.

Kenilworth (Castlegate "D") Coal Seam

The Kenilworth or Castlegate "D" seam is the highest coal of economic significance in the Standardville Quadrangle. It lies 55 to 67 m (180 to 220 ft) above the Aberdeen Sandstone and within a few meters of the top of the Kenilworth Sandstone near the eastern edge of the quadrangle. This coal has, in the past, been mined in the areas of Sowbelly Gulch, Hardscrabble Canyon, and Price River Canyon. It is presently being mined in the Sowbelly Gulch area. At Kenilworth, to the east, it is 5.8 m (19 ft) thick. It crops out throughout most of the quadrangle, but areas of minable coal thickness are restricted to the northeastern corner. The Kenilworth or Castlegate "D" reaches a maximum of 4.0 m (13.0 ft) and averages about 1.2 m (4.0 ft) thick. Overburden ranges between 0 and 671 m (0 and 2200 ft).

OIL AND NATURAL GAS

As of yet, no wells have been drilled in the Standardville Quadrangle for oil or natural gas. However, prospects of finding hydrocarbons in stratigraphic traps associated with the intertonguing of littoral sandstones and marine shales in the Mancos Shale at depth in the northern part of the quadrangle should be considered.

WATER RESOURCES

The only perennial stream in the Standardville Quadrangle, the Price River, passes through the extreme northeast corner of the quadrangle. Two others, the North Fork of the Gordon Creek and the stream in Spring Canyon, run almost all year, except for late summer. Most other streams run only in winter and spring and during flash floods that occur with moderate frequency in the summer months. Several springs also occur in the area, but these also tend to dry up in the latter part of the summer.

SUMMARY

Bedrock sedimentary units exposed within the Standardville Quadrangle are of Late Cretaceous age and range from the upper Mancos Shale to the lower part of the North Horn Formation. A Tertiary igneous dike crops out near the southeast corner of the quadrangle. Unconsolidated deposits include stream alluvium, weathered Mancos Shale lag, and pediment gravel.

For detailed mapping, the Mancos Shale was subdivided into 15 sandstone and 18 shale units. The Dempseyville, Bull Point, and Wildcat Sandstones are formally proposed as new members of the Mancos Shale.

The Star Point Sandstone includes the Panther and Storrs Sandstones, which are separated by a tongue of the Mancos Shale.

The Blackhawk Formation is separated from the Star Point Sandstone by a tongue of Mancos Shale and includes the Spring Canyon Sandstone, mudstone 1, Aberdeen Sandstone, mudstone 2, Kenilworth Sandstone, and mudstone 3–4 members.

Littoral sandstones of the Mancos Shale, Star Point Sandstone, and Blackhawk Formation represent deposition on wave-dominated deltas that prograded eastward into the Mancos Sea. These transitional sandstones, situated between open-marine and terrestrial environments, were subdivided into four facies. These facies, I through IV, represent the prodelta, lower shore face, upper shore face, and foreshore environments, respectively. Terrestrial deposits of mudstone, shale, sandstone, and coal generally occur above facies IV. Facies I–IV can be used in forming predictive models in the exploration for coal and hydrocarbons and in refining paleogeographic interpretations. Thick, laterally extensive coals generally occur directly on top of facies IV sandstone; therefore, if no facies IV is present, no major coal deposits are expected.

The Castlegate Sandstone, Price River Formation, and North Horn Formation are dominated by terrestrial deposits and represent the withdrawal of the Mancos Sea from the area and the filling in of the Upper Cretaceous and lower Tertiary seaway.

Coal is by far the most obvious economic resource of the Standardville Quadrangle. Seven coal seams of sufficient thickness for mining are located in the quadrangle. These are the Spring Canyon A sub 3, B sub 2, and C sub 1, Castlegate "A," "B," and "C," and Kenilworth or Castlegate "D" seams. The Spring Canyon A sub 3 and Kenilworth or Castlegate "D" coals are currently being worked in the quadrangle. These seven seams and several other minor coals are potential targets for in situ coal gasification. Reserve estimates indicate about 454 million tons of minable coal within the Standardville Quadrangle.

APPENDIX

Type sections and locations for the Dempseyville, Bull Point, and Wildcat Canyon Sandstones

The type section for the Dempseyville, Bull Point, and Wildcat Canyon Sandstones is located on the southwest flank of Bull Point in section 26, T. 13 S, R. 8 E. Starting point is at the top of the Emery Sandstone 5 tongue at Oak Spring (NW ¼, NE ¼, NE ¼, section 35, T. 13 S, R. 8 E).

Top of Wildcat Canyon Sandstone

Unit	*Description*	*Unit Thickness (meters)*	*Cumulative Thickness (meters)*
10	Sandstone, fine-grained, calcareous, with abundant organic material, some coalified; medium gray to medium orange gray, weathers light orange gray; bedding 8 to 17 cm; faint cross-stratification; moderate bioturbation with horizontal and vertical annelid worm burrows prominent; upper contact with Mancos Shale map unit 15 sharp; forms ledge.	1.5	144.3
9	Sandstone, fine-grained, calcareous, abundant organic material; light orange gray, weathers medium orange gray; highly bioturbated—no laminations apparent; many subspheroidal, calcareous nodules 2 to 15 cm in diameter; calcite crystals up to 7 cm embedded in sandstone; upper contact sharp; forms ledge.	1.8	137.3
8	Sandstone, very-fine-grained, interbedded with noncalcareous silty shale; silty shale is dark gray, weathers botryoidally to light gray; sandstone is medium orange gray, weathers light orange gray; bedding 10 to 20 cm; horizontal laminations observed near top of unit; moderately bioturbated with *Ophiomorpha* and annelid worm burrows; upper contact sharp; forms ledge or covered slope.	3.7	131.1
	Base of Wildcat Canyon Sandstone and top of Mancos Shale map unit 14		
7	Shale, silty, medium to dark gray, weathers light to medium gray; upper contact with Wildcat Canyon sandstone gradational; forms weathered slope, in places covered.	20	128.1
	Base of Mancos Shale map unit 14 and top of Bull Point Sandstone		
6	Sandstone, calcareous, fine-grained, moderate organic debris; medium orange gray, weathers medium orange; bedding 3 to 30 cm; abundant vertical and horizontal annelid worm burrows, other sedimentary structures obscure; upper contact with Mancos Shale map unit 14 gradational; forms ledge.	5.5	108.1
5	Sandstone, same as unit 8, except that the upper contact is gradational and no horizontal laminations were observed.	9.1	93.5
	Base of Bull Point Sandstone and top of Mancos Shale map unit 13		
4	Shale, same as unit 7 of Mancos Shale map unit 14; mostly covered by pediment gravel.	27	84.4
	Base of Mancos Shale map unit 13 and top of Dempseyville Sandstone		
3	Sandstone, fine-grained, light orange gray, weathers medium or-	3.0	57.4

	ange gray; bedding 20 to 91 cm with no apparent stratification; heavily bioturbated with *Ophiomorpha*, annelid worm burrows, and Terebellina; pillow structure 2.2 m across and 0.8 m thick at base of unit; upper contact sharp; forms ledge.		
2	Sandstone, same as unit 8 of Wildcat Canyon Sandstone, but with 60% very fine-grained sandstone and 40% silty shale.	3.7	50.7

Base of Dempseyville Sandstone and top of Mancos Shale map unit 10–12

1	Shale, same as unit 7 of Mancos Shale map unit 14.	47	47

Base of Mancos Shale map unit 10–12 and top of Emery Sandstone 5 tongue

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