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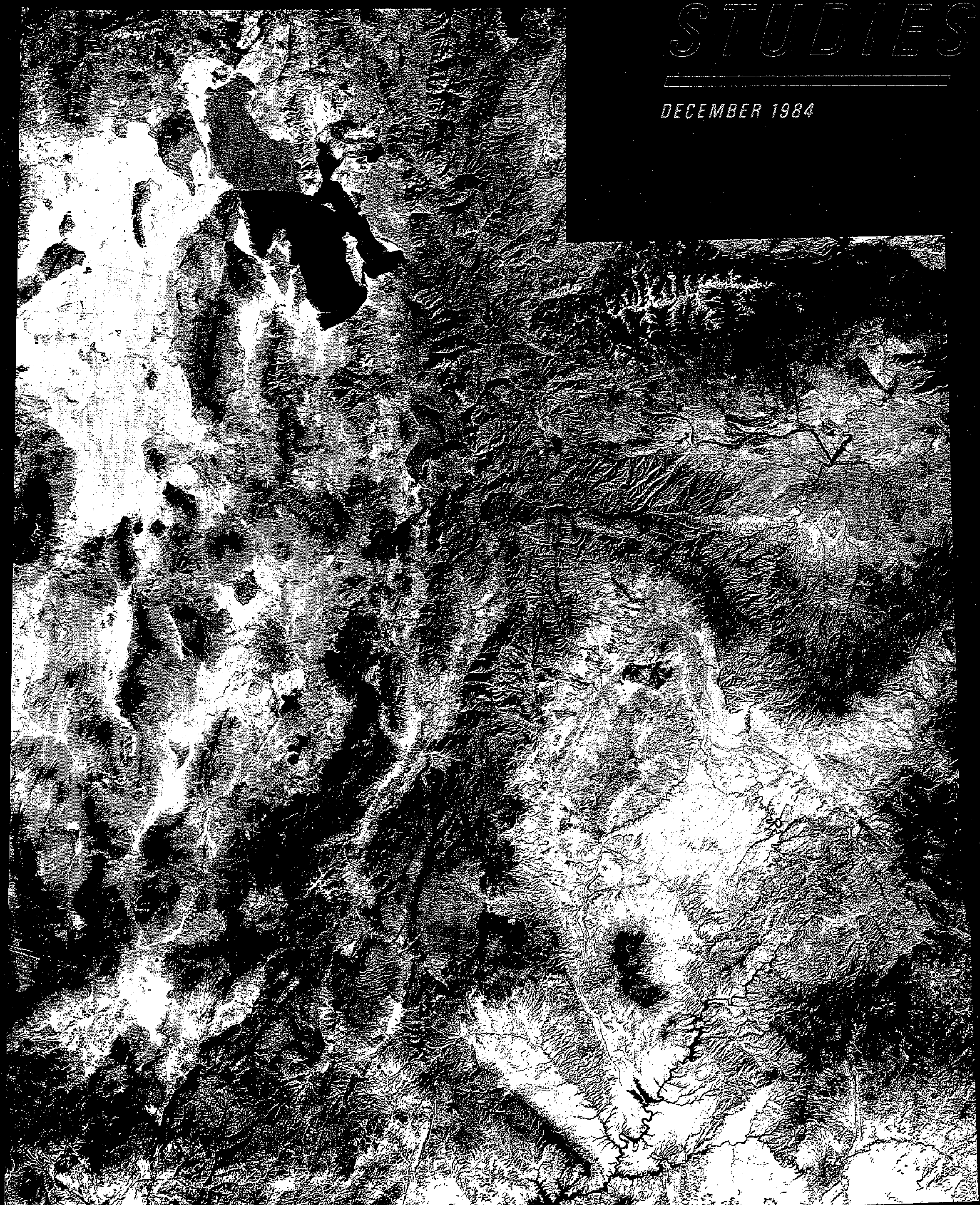

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THE GLORY OF GOD IS INTELLIGENCE

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Geology of the Steele Butte Quadrangle, Garfield County, Utah*

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ABSTRACT

The Steele Butte Quadrangle is located in the Henry Mountains coalfield of southeastern Utah.

Upper Jurassic and Lower Cretaceous rocks exposed in the quadrangle indicate deposition in interdeltaic-coastal, shallow-marine, tidal-flat, fluvial, lacustrine, and eolian environments. Upper Cretaceous Dakota Sandstone and Mancos Shale represent marine, deltaic, and interdeltaic sediments deposited in response to continually shifting deltaic lobes.

Laramide deformation during Late Cretaceous to early Tertiary time produced the Henry Mountains syncline. Eocene laccolithic intrusions created associated faults and folds.

The Muley Canyon Sandstone contains potential coal resources suitable for strip mining. Coal occurs in a carbonaceous zone of 1–4 seams that average 2–3 m total thickness with a maximum of 6 m. Overburden is generally less than 45 m (150 ft) thick across much of the quadrangle. Economic coal deposits are limited to the northern two-thirds of the quadrangle. Coal in the southern third was eroded during deposition of surrounding fluvial sandstones.

INTRODUCTION

Muley Canyon Sandstone in the Steele Butte Quadrangle contains coal deposits suitable for strip mining, prompting interest in the area. Although previous studies have outlined regional geology of the Henry Mountains, this more detailed study documents the coal resources, stratigraphy, and structure of the quadrangle.

A depositional model is developed for the widespread Blue Gate Shale, Muley Canyon Sandstone, and Masuk Shale members of the Mancos Shale. This model presents a predictable pattern of coal distribution in the quadrangle and provides criteria to combine related rocks into stratigraphic units.

LOCATION AND ACCESSIBILITY

The Steele Butte Quadrangle is located in Garfield County, about 35 km southwest of Hanksville, within the Henry Mountains coalfield of southeastern Utah (fig. 1). Improved dirt roads provide access from Utah 24 into the study area. Access is good except when sporadic late summer storms hamper travel.

METHODS

Fieldwork was conducted from June through September, 1982. Stratigraphic sections were measured of all exposed sedimentary units. Field mapping was completed on 1:31,680 aerial photographs and transferred to a 1:24,000 topographic quadrangle. A geologic map and cross section, at 1:24,000 scale, are published in the Utah Geological and Mineral Survey Map Series (Whitlock 1984) and are not duplicated in this report.

Fourteen coal sections were measured and channel samples of coal from the Muley Canyon Sandstone were collected at 2-km (1.5-mi) intervals along the outcrop trace. Additional coal sections were measured at 0.3-km (0.25-mi) intervals. Coal samples were submitted to the Utah Geological and Mineral Survey for analysis. Results of analysis will be published in a future survey publication of the Henry Mountains coalfield.

Electrical and lithologic logs were used with field data, to construct the coal isopach map, structure contour map, and structural cross section.

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

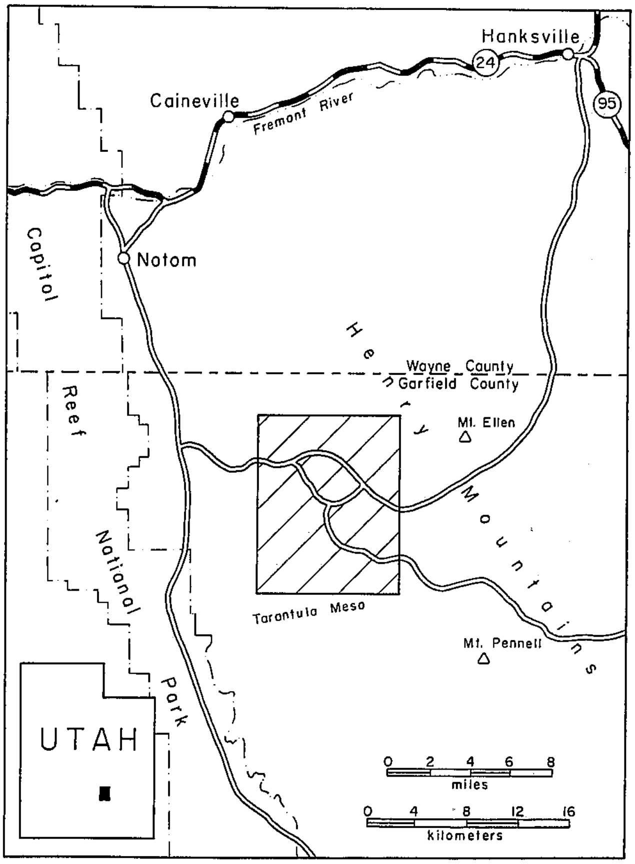

FIGURE 1.—*Index map showing location of the Steele Butte Quadrangle.*

PREVIOUS WORK

The Henry Mountains region was first studied by Gilbert (1877) who described the general stratigraphy and structure. Hunt (1946, Hunt and others 1953) completed a more detailed investigation of the area, and Doelling and Graham (1972) and Doelling (1975) studied the regional geology, emphasizing the economic resources. Uresk (1979) and Hill (1982) concluded the Ferron Sandstone resulted from fluvial-dominated deltaic processes. In the Utah Geological Association Henry Mountains Symposium of 1980, Stokes reported on the Triassic and Jurassic stratigraphy; Peterson, Ryder, and Law described the stratigraphy, sedimentology, and regional correlations of the Cretaceous System; and Law presented a regional study of depositional patterns in the Muley Canyon Sandstone.

ACKNOWLEDGMENTS

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STRATIGRAPHY AND SEDIMENTATION

GENERAL STATEMENT

Rocks exposed in the Steele Butte Quadrangle are summarized in figure 2. Outcrop locations are displayed on the geologic map published in the Utah Geological and Mineral Survey Map Series (Whitlock 1984).

Mesozoic rocks have been upwarped by Eocene igneous intrusions. Jurassic units exposed in the northeast corner of the quadrangle include the Entrada Sandstone, Curtis Formation, Summerville Formation, and Salt Wash and Brushy Basin Members of the Morrison Formation. Cretaceous Cedar Mountain Formation, Dakota Sandstone, and Tununk Shale and Ferron Sandstone Members of the Mancos Shale are exposed only near igneous intrusions in the northeast corner. Blue Gate Shale, Muley Canyon Sandstone, and Masuk Shale Members of the Mancos Shale and the Tarantula Mesa Sandstone are exposed throughout the quadrangle. "Beds on Tarantula Mesa" (Peterson and Ryder 1975, p. 180–81) are preserved in the center of the mesa near the southern margin of the map area. Early Tertiary igneous intrusions of Mount Ellen have penetrated the sedimentary rocks and crop out in the northeast corner of the map area.

Unconsolidated Quaternary deposits occur as pediment gravel and lobes of alluvial terrace gravel in the eastern half of the quadrangle and eolian loess and sand on Tarantula Mesa.

JURASSIC SYSTEM

Entrada Sandstone

Hunt and others (1953, p. 70–72) reported that the Entrada Sandstone ranges in thickness from 91 m (300 ft) at the southern end of the San Rafael Swell to 213 m (700 ft) in the southern Henry Mountains. They described west-to-east facies variations, as a red, earthy, thin- to thick-bedded, silty sandstone in the west and clean, massive, cliff-forming sandstone in the east.

Entrada Sandstone crops out in the northeastern corner of the quadrangle near igneous intrusions. Beds are exposed as reddish sandstone ledges in canyon exposures in the NE ¼, section 14, T. 31 S, R. 9 E. In the extreme northeast corner they cap a ridge above an igneous intrusion.

No complete section of Entrada Sandstone is exposed in the quadrangle; however, a partial section was measured south of Dugout Creek in the SW ¼, section 24, T. 31 S, R. 9 E (Morton 1984, appendix). There the formation is pale red to very pale orange, very fine to fine-grained sandstone and minor siltstone, characteristic of Hunt and others' earthy facies. Sandstone is cemented by calcite and contains minor gypsum. The rocks are typically very thin to medium bedded, although one unit is massive. The formation weathers to ledges and slopes with low outcrops (fig. 3). Smith (1976, p. 140) interpreted units similar to the earthy facies as deposited in an interdeltaic-coastal environment. No fossils were found in the Entrada Sandstone.

The base of the Entrada Sandstone is not exposed in the quadrangle. The upper contact with the Curtis Formation

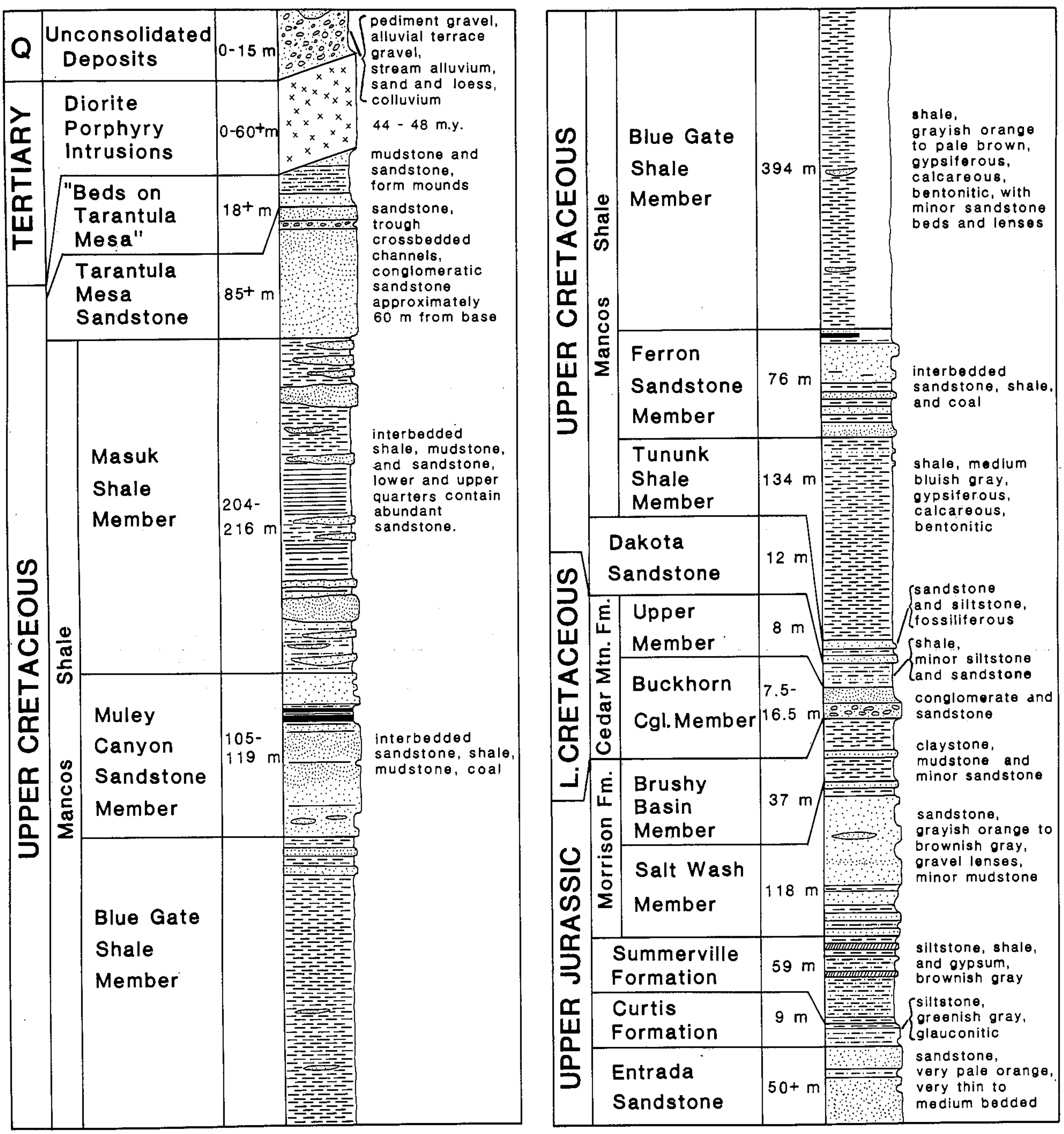


FIGURE 2.—*General stratigraphic column of rocks exposed in the Steele Butte Quadrangle.*

is disconformable throughout most of the region (Hunt and others 1953, p. 71), although evidence of erosion was not apparent in limited exposures in this quadrangle.

Curtis Formation

The greenish sandy Curtis Formation thins from 53 m (175 ft) at the southern edge of the San Rafael Swell to a feather edge at the northern end of Tarantula Mesa (Hunt and others 1953, p. 72). Hunt interpreted this thinning as a result of the southward change from Curtis to Summerville lithology.

Curtis Formation is exposed in two areas in the quadrangle. In the NE ¼, section 14, T. 31 S, R. 9 E, it is a thin greenish gray siltstone that forms a ledgy slope above the Entrada Sandstone. That outcrop is truncated at the north by an east–west-trending fault. North of that fault the formation forms a thin band west and southwest of a broad ridge capped by Entrada Sandstone.

The Curtis Formation measured south of Dugout Creek (Morton 1984, appendix) in the SW ¼, section 24, T. 31 S, R. 9 E, is 9 m of glauconitic, calcareous siltstone and subordinate shale. It is light greenish gray and weathers very light greenish gray, in contrast to the adjacent red Entrada Sandstone and Summerville Formation. Bedding is thinly laminated to thin bedded, with abundant ripple marks, and weathers to a ledge-and-slope topography (fig. 3). Working in the San Rafael Swell, Smith (1976, p. 154) concluded that the Curtis Formation was deposited in warm, shallow, low-energy marine waters. Gilluly and Reeside (1928, p. 79) reported middle Upper Jurassic marine fossils from the Curtis Formation in the San Rafael Swell. The upper contact with the Summerville Formation is gradational and conformable.

Summerville Formation

Hunt and others (1953, p. 73) described the Summerville Formation as sandstone and shale distinguished by regular bedding and reddish brown color. The formation ranges from 76 m (250 ft) thick in the northern part of the region to 12 m (40 ft) thick near Halls Creek, approximately 30 km south of the quadrangle.

The Summerville Formation is exposed in the NE ¼, section 14, T. 31 S, R. 9 E, where it occurs in a continuous outcrop across two ridges. An east–west-trending fault has uplifted the northern outcrop belt. The formation erodes to ledges and slopes between the resistant Entrada Sandstone and the Salt Wash Member of the Morrison Formation (fig. 3).

A complete section of the Summerville Formation was measured immediately east of the quadrangle, south of Dugout Creek (Morton 1984, appendix). There it is 59 m of pale reddish brown to light brownish gray siltstone and shale, interbedded with reddish, iron-stained gypsum.

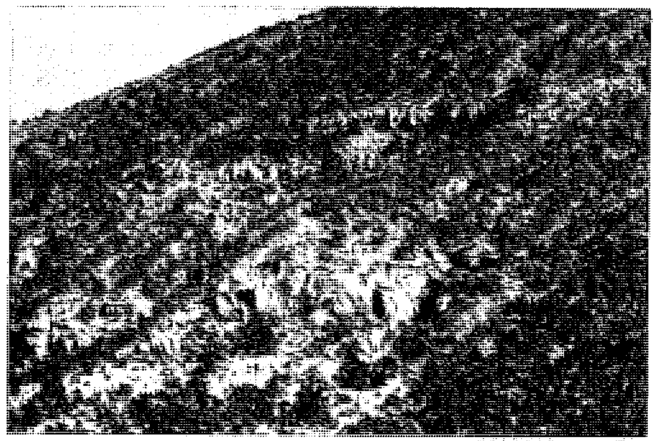


FIGURE 3.—*View southeast across Dugout Creek of Jurassic Entrada Sandstone (1), Curtis Formation (2), Summerville Formation (3), and Salt Wash Member of the Morrison Formation (4).*

Siltstone and shale contain abundant disseminated calcite and gypsum. Stanton (1976, p. 60) interpreted similar lithologies of the Summerville Formation in the San Rafael Swell as tidal-flat deposits.

The Summerville Formation is defined as Late Jurassic on the basis of its position between the fossiliferous Curtis and Morrison formations (Gilluly and Reeside 1928, p. 80).

Contact with the Curtis Formation is gradational, and the boundary was mapped above the uppermost greenish, glauconitic siltstone. The Summerville Formation–Morrison Formation contact is a prominent disconformity in the northern part of the region but becomes less apparent toward the south (Hunt and others 1953, p. 73). An unconformable boundary was not apparent in this quadrangle. Contact with the Morrison Formation was mapped at the top of the uppermost massive gypsum of the Summerville Formation.

Morrison Formation

The Morrison Formation is 150–180 m (500–600 ft) of conglomerate, sandstone, mudstone, shale, limestone, massive clay, and gypsum (Hunt and others 1953, p. 75–76). Hunt and others divided the formation into the lower Salt Wash Sandstone Member and upper, unnamed clayey member. The clayey unit is the Brushy Basin Member of Gregory (1938, p. 59).

Salt Wash Member. In the Henry Mountains region, the Salt Wash Member is composed of 46–145 m (150–475 ft) of lenticular claystone and shale with interbedded lenses of sandstone and conglomerate (Hunt and others 1953, p. 75).

The Salt Wash Member is widely exposed in the northeast corner of the quadrangle. North of Dugout Creek, a normal fault has offset the western half of the Salt Wash outcrop and exposed seven prominent sandstone ledges. This number contrasts with three prominent sandstones in the measured section and indicates the stratigraphy is repeated because of faulting. South of Dugout Creek, an igneous intrusion caused minor reverse faults in the Salt Wash Member.

A section of the Salt Wash Member was measured south of Dugout Creek in the SW ¼, section 24, and NW ¼, section 25, T. 31 S, R. 9 E (Morton 1984, appendix). There the member is 118 m of grayish orange to brownish gray sandstone interbedded with subordinate reddish and greenish, bentonitic mudstone. Sandstone is medium grained to granular in the upper 46 m and very fine to fine grained, with minor gravel lenses, in the lower part. Sandstone and mudstone are cemented by calcite and contain minor iron oxide. Thick to massive bedded sandstone forms prominent cliffs and laminated to thin-bedded sandstone and mudstone form minor ledges and slopes (fig. 3). Lenses of cross-bedded, gritty sandstone occur in the massive cliffs. Craig (1955, p. 150–51) interpreted the Salt Wash Member as fluvial-channel and floodplain deposits.

Hunt and others (1953, p. 75) reported a distinct erosional unconformity separating Morrison and Summerville beds in several localities but noted the contact normally has to be traced over a considerable distance to distinguish the disconformity. There was no disconformity apparent between Salt Wash Sandstone and Summerville Formation in the map area.

Brushy Basin Member. Hunt and others (1953, p. 75, 76, pl. 4) reported this upper clayey part of the Morrison Formation is 38–114 m (124–375 ft) thick and consists of a lower variegated clay member and an upper gray clay member. Craig (1955, p. 155–56, fig. 29) included the clay units of the Morrison Formation in the Brushy Basin Member in the Henry Mountains region.

The Brushy Basin Member crops out as broad slopes in the northeast corner of the quadrangle (fig. 4). North of Dugout Creek, the Buckhorn Conglomerate or gravel cap the Brushy Basin slope. The member is associated with an igneous intrusion and truncated by a fault south of Dugout Creek.

A section of Brush Basin Member was measured 0.4 km north of Dugout Creek in the NE ¼, section 23, T. 31 S, R. 9 E. There the member is 37 m of interbedded pale greenish yellow claystone and moderate red mudstone. Bentonite in the claystone and mudstone give the soil a "popcorn" texture. Beds are thinly laminated to very thin bedded and form a slope with minor ledges of siltstone and sandstone. Brushy Basin sediments were deposited in fluvial and lacustrine environments on a broad, undissected plain, with bentonitic clay resulting from volcanic ash falls (Craig 1955, p. 159–60).

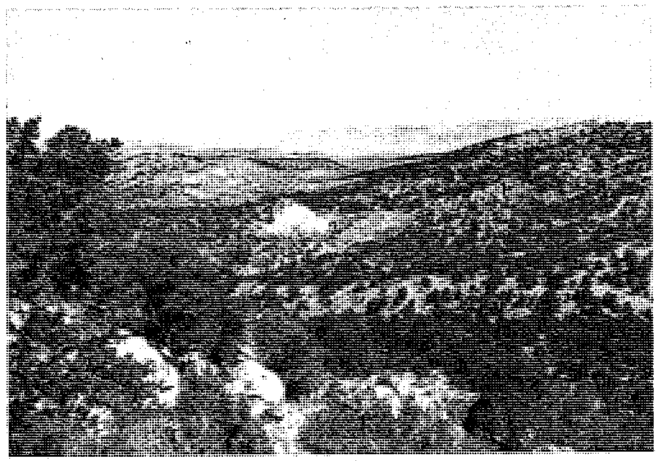


FIGURE 4.—*Brushy Basin Member (2) forms a slope between ledges of Salt Wash Member of the Morrison Formation (1) and the Buckhorn Conglomerate Member of the Cedar Mountain Formation (3).*

Contact with the Salt Wash Member is conformable. The boundary was mapped at the top of the uppermost Salt Wash sandstone, below Brushy Basin claystone and shale.

CRETACEOUS SYSTEM

Cedar Mountain Formation

The Cedar Mountain Formation consists of the Buckhorn Conglomerate Member and an upper shale member and was named for exposures along the southwestern flank of Cedar Mountain, Emery County, Utah (Stokes 1944, p. 965–66). The Buckhorn Conglomerate was originally defined as a formation but was reduced to a member of the Cedar Mountain Formation because of its discontinuous nature (Stokes 1952, p. 1774). The Cedar Mountain Formation is Lower Cretaceous and is unconformably overlain by the Dakota Sandstone (Peterson 1980, p. 152–53).

Buckhorn Conglomerate Member. The Buckhorn Conglomerate occurs in outcrops separated by minor faults and younger gravel cover. The member erodes to sandstone and conglomerate slopes and ledges between the less resistant Brushy Basin Member and an upper shale member of the Cedar Mountain Formation (fig. 4).

A section measured 0.3 km north of the road in section 23, T. 31 S, R. 9 E, contains 16.5 m of brownish gray to yellowish brown sandstone and conglomerate. Sandstone is thin bedded with cross laminations and composed of fine-grained quartz with calcite cement and abundant iron oxide. Conglomerate is composed of chert and quartzite pebbles in a medium-grained sand matrix. It is massively bedded and forms a cliff. The member is extremely variable in thickness and composition. A section measured 50–100 m southeast is composed of 7.5 m of calcareous sandstone. The Buckhorn Conglomerate was deposited by fluvial and eolian processes (Stokes 1944, p. 976–77). Throughout the Colorado Plateau, an unconformity at the base of the Buckhorn Conglomerate is represented by truncation of the Brushy Basin Member where shales are cut and channeled (Stokes 1944, p. 976).

Upper Member. The upper member of the Cedar Mountain Formation occurs in contact with the Buckhorn Conglomerate Member in sections 23 and 26, T. 31 S, R. 9 E, north and south of Dugout Creek. Alluvial terrace gravel and slope wash cover equivalent beds to the north.

A section of the upper member was measured 0.3 km north of the road in section 23, T. 31 S, R. 9 E. There the member is 8.0 m of light brownish gray shale with interbedded minor sandstone and siltstone. Shale is carbonaceous in the upper half and silty in the lower half. The entire unit is thinly laminated to laminated and forms a slope (fig. 5). Stokes (1944, p. 977–78) suggested that the upper member formed from reworked Brushy Basin shales.

FIGURE 5.—*Fault has placed the Buckhorn Conglomerate (1) against the upper member (2) of the Cedar Mountain Formation and the Dakota Sandstone (3). View immediately north of the road near Dugout Creek.*

Fossils collected from the upper part of the formation indicate an Upper Cretaceous age. Contact with the overlying Tununk Shale Member of the Mancos Shale is gradational and conformable.

Dakota Sandstone

Several authors (Stokes 1944, Craig and others 1961) have considered the problem of correlating the Dakota Sandstone and Cedar Mountain Formation. Peterson and others (1980, p. 153) concluded that the Dakota Sandstone is stratigraphically higher than the Cedar Mountain Formation and they are separated by an unconformity. They described the Dakota Sandstone as interbedded gray sandstone, carbonaceous mudstone, and coal. The formation averages 10 m (35 ft) thick but reaches a maximum 30 m (100 ft) thick.

Dakota Sandstone crops out as a series of slopes and ledges north and south of Dugout Creek. The outcrop is disrupted by normal faults and is often covered by pediment gravel and alluvial gravel north of Dugout Creek. South of Dugout Creek the unit crops out in association with an igneous intrusion.

A section measured in the north half of section 23, T. 31 S, R. 9 E, includes 12 m of interbedded pale orange to grayish yellow sandstone and siltstone. Units are composed of silt-size to fine-grained quartz sand with calcareous cement and minor gypsum and iron oxide. *Gryphaea* and *Ostrea* shells occur throughout the formation, locally comprising up to 50% of individual beds. Beds are thinly laminated to thin bedded, but often bedding is strongly bioturbated. The formation weathers to a ledge-and-slope topography (fig. 5). The Dakota Sandstone represents a transgressive sequence of fluvial deposits at the base, overlain by beach and shallow-marine deposits (Lawyer 1972).

Mancos Shale

Mancos Shale blankets most of the Steele Butte Quadrangle. Gilbert (1877) divided the Mancos Shale into Tununk Shale, Tununk Sandstone, Blue Gate Shale, Blue Gate Sandstone, and Masuk Shale in the Henry Mountains region. Tununk and Blue Gate Sandstones were renamed Ferron and "Emery" Sandstones for similar stratigraphic units on the Wasatch Plateau (Hunt 1946, p. 8). Maxfield (1976) and Peterson and others (1980) suggested, on the basis of paleontologic studies, that the Masuk Shale and "Emery" Sandstone Members on the Wasatch Plateau correlate to the Blue Gate Shale in the Henry Mountains region. Smith (1983) renamed the "Emery" Sandstone in the Henry Mountains area as the Muley Canyon Sandstone for exposures south of Tarantula Mesa, at the head of Muley Canyon. The name *Masuk Shale Member* is retained because the type locality is in the Henry Mountains region. Present usage is shown in figure 2.

Tununk Shale and Ferron Sandstone are exposed only in the northeast corner of the quadrangle. The Blue Gate Shale, Muley Canyon Sandstone, and Masuk Shale Members are of major interest because of their extensive outcrops and close association with the economically important coal-bearing strata of the Muley Canyon Sandstone.

Tununk Shale Member. Peterson and others (1980, p. 155) reported the Tununk Shale is 160–220 m (532–717 ft) thick and is composed of medium to dark gray, bentonitic shale.

Tununk Shale crops out as nonresistant slopes capped by Ferron Sandstone or pediment gravel in a belt that extends from the NW ¼, section 23, to the SW ¼, section 11, T. 31 S, R. 9 E (fig. 6). South of Dugout Creek, in section 26, T. 31 S, R. 9 E, an igneous intrusion has isolated an outcrop of the Tununk Shale above the intrusion.

A section of Tununk Shale was measured along a traverse from the NW ¼, section 23, to the center of the section 14 and section 15, T. 31 S, R. 9 E, boundary. There the member is 134 m of medium bluish gray shale with thin beds of yellowish orange sandstone. Thickness of the measured section (134 m), compared to other sections (160–220 m) in the Henry Mountains region, may have resulted from errors in measurements where exposures are covered by pediment gravel. Shale is cemented with calcite and contains gypsum, bentonite, and silt that cause "punky"- and "popcorn"-textured soil. Bedding is thinly laminated to laminated and weathers to a slope with minor sandstone ledges.

Peterson and others (1980, p. 155) concluded that the Tununk Shale is late Cenomanian to middle Turonian age, on the basis of the occurrence of ammonites and pelecypods. Lessard (1973) suggested the member was deposited in shallow to open marine environments as the sea transgressed then regressed in response to development of Ferron deltas.

Contact with the Ferron Sandstone is gradational, and the boundary is placed at the basal sandstone ledge of the Ferron Member.

Ferron Sandstone Member. Hunt and others (1953, p. 81–83, fig. 21) divided the Ferron Sandstone into a lower unit of interbedded sandstone and shale, overlain by a massive sandstone unit, and capped by lenticular carbonaceous shale, coal, and sandstone. Thickness ranges from 91 m (300 ft) along the western edge of the region to 46 m (150 ft) on the eastern edge of the basin.

Ferron Sandstone crops out in the northeast corner of the quadrangle as prominent cliff-forming sandstone overlying interbedded sandstone and shale (fig. 7). Shale, coal, and sandstone beds at the top of the unit are easily eroded and covered by gravel.

A partial section of the Ferron Sandstone was measured from the SW ¼, section 11, to the SE ¼, section 10, T. 31 S, R. 9 E. There the member is 76 m of interbedded sandstone and shale, overlain by a massive cliff-forming sandstone, with carbonaceous shale on top. Alluvial terrace gravel covers the top of the unit. Morton (personal communication 1982) measured a section of the Ferron Sandstone in the NE ¼, section 12, T. 31 S, R. 9 E. Above the massive sandstone are 5 m of shale and coal capped by a calcareous sandstone. Sandstone in the lower part of the unit is yellowish orange to yellowish brown and very fine to fine grained with minor calcite and iron oxide cement.

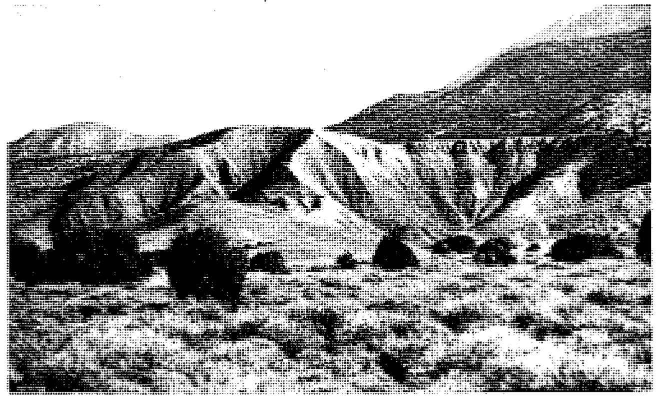


FIGURE 6.—*Tununk Shale slope capped by pediment gravel in the northeast corner of the quadrangle.*

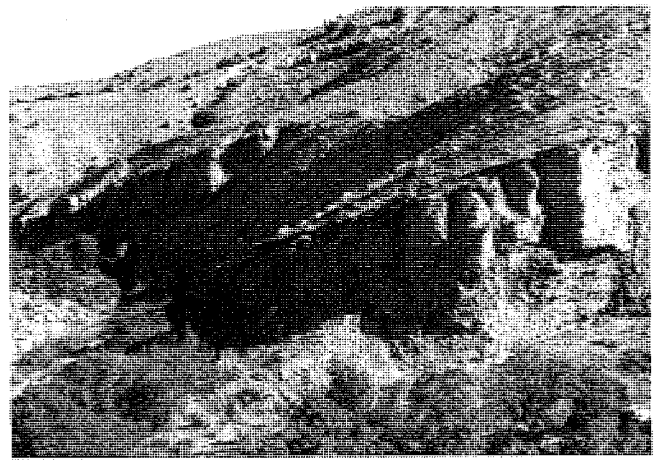


FIGURE 7.—*Right side of the photograph shows Ferron Sandstone ledges above Tununk Shale slope, exposed in Dry Wash.*

It is very thin to very thick bedded with trough crossbeds, channels, and current ripples. Medium gray to brownish gray silty shale is interbedded with the sandstone and weathers to a ledge-and-slope topography (fig. 7).

The cliff-forming sandstone is very pale orange, very fine to fine grained, contains kaolinite and iron oxide, and is thick to massively bedded. Laminated light bluish gray shale forms a slope above the massive sandstone.

Contact with the Blue Gate Shale is locally disconformable (Hunt and others 1953, p. 83). Morton (personal communication 1982) reported a pebble conglomerate at the base of the Blue Gate Shale in section 13, T. 32 S, R. 9 E, that documents the disconformity. Peterson and others (1980, p. 159) suggested, because of the absence of six ammonoid faunal zones, that the erosional unconformity represents most of late Turonian and all of Coniacian time. Uresk (1979) and Hill (1982) determined that the Ferron Sandstone formed from fluvial and deltaic processes as the Notom Delta prograded eastward.

Blue Gate Shale Member. The Blue Gate Shale Member is similar in appearance to the Tununk Shale. Hunt and others (1953, p. 83) described the member as 425 m (1,400 ft) or dark gray shale. They divided it into a homogeneous shale unit in the lower two-thirds, overlain by a unit of interbedded shale and platy sandstone.

Outcrops of Blue Gate Shale occur along the east side of the quadrangle in a belt of north–south-trending cuestas. An east-facing slope of Blue Gate Shale is capped by the resistant Muley Canyon Sandstone Member (fig. 8). An isolated outcrop occurs as an inlier in a deep canyon in the SW ¼, section 2, T. 32 S, R. 9 E. There the massive cliff-forming Muley Canyon Sandstone has been breached, exposing interbedded shale and sandstone of the Blue Gate Shale (fig. 9).

FIGURE 8.—*Prominent cuesta on east side of quadrangle, composed of Blue Gate Shale slope capped by Muley Canyon Sandstone. In the background, Masuk Shale flat and slope are capped by Tarantula Mesa Sandstone cliffs.*

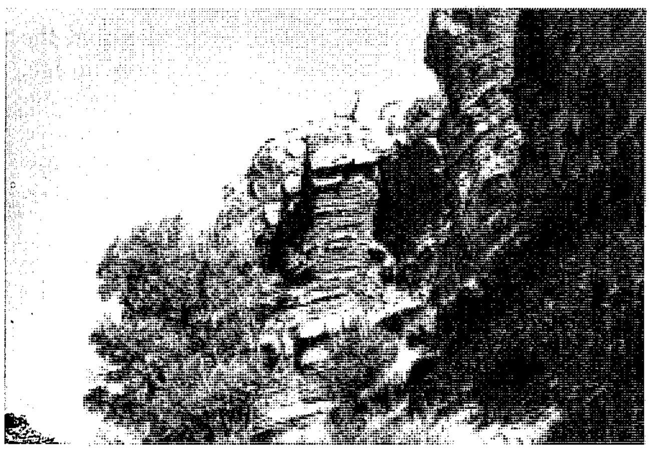


FIGURE 9.—*Interbedded sandstone and shale of Blue Gate Shale transitional facies, exposed in canyon in SW ¼, section 2, T. 32 S, R. 9 E.*

Blue Gate Shale, measured near Mud Spring, section 10, T. 31 S, R. 9 E, consists of 394 m of shale. The lower 194 m, including the Ferron Sandstone–Blue Gate Shale contact, is covered by alluvial terrace gravel, but isolated outcrops show these beds. Shale is olive gray to grayish orange; contains disseminated calcite, bentonite, and gypsum and gypsum stringers; and is thinly laminated to laminated. The upper 15 m of the member is interbedded shale and light brown sandstone that form a ledgy slope. Locally, at Stevens Narrows, ball-and-pillow structures occur in the sandstone. Smith (1983, appendix) measured a section of the Blue Gate Shale in the southeastern corner of the quadrangle in sections 13 and 14, T. 32 S, R. 9 E. There the member is 416 m of homogeneous shale, with interbedded sandstone in the upper 40 m.

Contact with the Muley Canyon Sandstone Member is gradational. The boundary was placed at the top of the interbedded shale and sandstone zone that is overlain by ledge-forming sandstone of the Muley Canyon Member. Peterson and others (1980, p. 159) reported the Blue Gate Shale is late Santonian to early Campanian in age on the basis of paleontologic evidence.

Blue Gate Shale sediments were deposited in normal-marine, prodelta and transition zone deltaic environments. The regressive sequence was deposited in response to progradation of the Muley Canyon Sandstone delta. Invertebrate fossils collected from the lower part of the Blue Gate Shale suggest deposition in normal-marine waters 60–120 m (200–400 ft) deep (Peterson and others 1980, p. 159). Benthonic foraminifera in the middle of the member indicate a shoaling seaway due to increasing proximity to the prograding shoreline (Maxfield 1976, p. 83).

The upper quarter of the Blue Gate Shale is interbedded sandstone and shale, characteristic of transition deposits between prodelta shale and delta front sandstone. Sand was deposited as storm waves initiated seaward transport of shoreface sand (Balsley 1982, p. 76). Ball-and-pillow structures in the transition facies at Stevens Narrows indicate rapid deposition of the sand onto water-saturated mud (Reinick and Singh 1973, p. 78). Hubert and others (1972, p. 1656) described ball-and-pillow structures in the transition facies in the Cody-Parkman Delta of Wyoming. These structures formed as sand was deposited on loosely packed deltaic mud on a surface that dipped 1°–2° seaward. Pillow structures are locally developed within the quadrangle, which suggests the prodelta surface had a slope of 1° or less across most of the area.

Muley Canyon Sandstone Member. The Muley Canyon Sandstone (Smith 1983), formerly identified as the Emery Sandstone, is the major coal-bearing unit in the Henry Mountains coal basin.

Hunt and others (1953, p. 84–85, 216–17) described the member as approximately 76 m (250 ft) of sandstone, shale, and coal. They placed the upper contact of the member at the top of the carbonaceous shale-coal zone and included all overlying sandstone in the Masuk Shale Member.

Doelling (with others 1972, 1975) divided the member into a lower unit of thick-bedded sandstone with minor shale; a middle cliff-forming sandstone unit; and an upper unit of coal and carbonaceous shale overlain by resistant sandstone.

Peterson (1975, with others 1980) described the Muley Canyon Sandstone at 91–136 m (298–446 ft) of sandstone, mudstone, and coal. He divided the member into a lower cliff-forming sandstone and an upper unit of interbedded sandstone, mudstone, shale, and coal. Peterson and others (1980) concluded that the Muley Canyon Sandstone is early Campanian on the basis of regional correlations and its association with the fossiliferous Masuk Shale Member.

Law (1980) divided the Muley Canyon Sandstone Member into a lower unit of regressive, marginal marine sandstone and an upper unit of fluvial- and tidal-deposited sandstone, siltstone, carbonaceous mudstone and shale, and coal. He mapped and measured the coal zone and completed a basinwide correlation of all coal sections measured by Hunt, Averitt, Miller, Doelling, Graham and himself.

Three additional sections of Muley Canyon Sandstone Member were measured during the present study: (1) one along Blind Trail, in the eastern half of section 27, T. 31 S, R. 8 E, of the Notom, Utah 15-minute Quadrangle, (2) one south of Steele Butte, in the western half of section 34 and the SE ¼, section 33, T. 31 S, R. 9 E, and (3) one at Stevens Narrows, in the SW ¼, section 14, and the NW ¼, section 23, T. 32 S, R. 9 E. The member is 105 m thick at Blind Trail, 109 m thick at Stevens Narrows, and 119 m thick south of Steele Butte.

The Muley Canyon Member is divided into three informal map units (fig. 10) designated as Muley Canyon-1: a lower unit of ledge and cliff-forming sandstone with minor shale; Muley Canyon-2: a middle unit of interbedded carbonaceous shale, coal, and lenticular sandstone; Muley Canyon-3: an upper unit of sandstone. They correspond with units mapped by Smith (1983) in the adjacent Mount Pennell 2 NW Quadrangle.

Muley Canyon-1. The Muley Canyon-1 unit holds up cuestas in the eastern half of the quadrangle (fig. 8) and forms a bench along Sweetwater and Dugout Creeks in the northwest corner of the quadrangle. The unit ranges in thickness from 75 m at Blind Trail to 72 m at Stevens Narrows to 63 m near Steele Butte. It is predominantly sandstone with minor partings or thin beds of shale. Sandstone varies from yellowish gray and light brown, in the lower two-thirds of the unit, to a lighter colored very pale orange and grayish yellow above. It is composed of

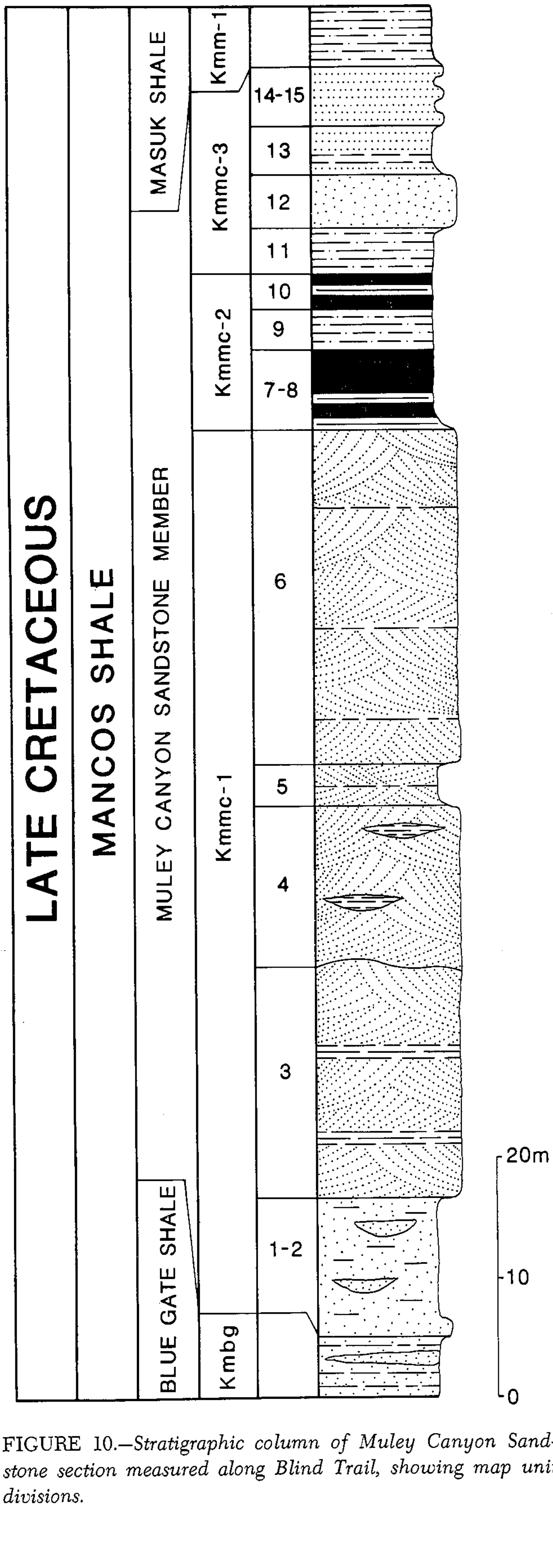


FIGURE 10.—*Stratigraphic column of Muley Canyon Sandstone section measured along Blind Trail, showing map unit divisions.*

75%–90% quartz, 5%–10% chert, and 5%–10% calcite cement. Sandstone in the lower part contains minor iron oxide, which stains the rocks orange.

Grain size coarsens upward from very fine sand at the base to medium-grained sand at the top, in the section measured at Blind Trail. Near Steele Butte and Stevens Narrows the sequence coarsens upward to medium- or fine-grained sandstone but then becomes very fine grained in the upper 1–10 m. The unit is generally medium to massive bedded, but may be thin bedded in the upper part, as seen in the upper 15 m near Steele Butte. Muley Canyon-1 beds hold up ledges separated by minor slopes in the lower quarter, but form massive cliffs in the upper part (fig. 11).

Several types of sedimentary structures occur in the Muley Canyon-1 beds. Horizontally bedded sandstone and shale with sandstone lenses occur near the base. Above the basal section, trough cross-beds and occasional horizontal beds occur in ledge- and cliff-forming sandstones, and ripple laminations occur in shale partings. Sandstone beds in the upper one-third of the unit contain trough cross-beds with horizontal beds at the top.

Trace fossils are sparse, although burrows were recognized at the base of one massive cliff-forming unit at Blind Trail, and *Ophiomorpha*? was noted in one outcrop in the SW ¼, section 15, T. 31 S, R. 9 E, south of Dry Wash. Peterson and others (1980, p. 161) identified *Ophiomorpha, Arenicolites,* and *Thalassinoides* in the unit in the central part of the Henry Mountains region.

Contact with the Muley Canyon-2 unit is sharp and was mapped at the upper boundary of the cliff-forming sandstone, which is overlain by coal or carbonaceous shale.

Sedimentary structures and a coarsening-upward sequence in the Muley Canyon-1 sandstone indicate deposition along a prograding, wave-dominated shoreline. Muley Canyon-2 delta plain sediments suggest the Muley Canyon-1 sequence was deposited in a wave-dominated deltaic environment, instead of a barrier island capped by lagoonal deposits. Thick, laterally extensive Muley Canyon-1 sandstone is characteristic of a wave-dominated deltaic sequence in which sediments are reworked along the shoreline by marine processes. This sand body contrasts with lobate or digitate sands of fluvial- or tidal-dominated deltaic environments.

The lower part of Muley Canyon-1 section is flat-bedded, very fine-grained sandstone and subordinate shale. Sandstone contains minor oscillation ripples. These beds comprise the lower 40 m in the section south of Steele Butte, but only the lower 10 m along Blind Trail. The rocks represent the lower shoreface facies of the deltaic sequence. Balsley (1982, p. 79) described a similar sequence of rocks in the Blackhawk Formation. He also reported storm-produced hummocky stratification; however, this structure was not recognized in this facies within the quadrangle.

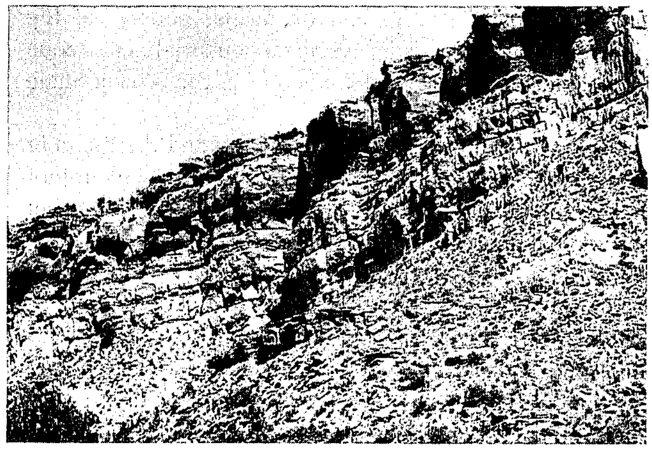


FIGURE 11.—*Massive sandstone cliffs of Muley Canyon-1 unit exposed along Blind Trail.*

Lower shoreface deposits result from sedimentary processes below effective wave base. Horizontal beds with minor ripples form during fair weather, and hummocky stratification results as storm waves erode fair-weather structures to form undulatory surfaces (Balsley 1982, p. 90).

Above the lower shoreface deposits is massive, trough cross-bedded sandstone with minor thin- to medium-bedded sandstone and laminated shale. The sandstone coarsens upward from very fine grained, at the base, to fine or medium grained at the top. This sequence comprises the upper 60 m of the Muley Canyon-1 unit at Blind Trail and approximately 20 m near Steele Butte. Deposits are characteristic of the upper shoreface facies described by Balsley (1982, p. 97–99) in the Blackhawk Formation of east central Utah. He stated that upper shoreface deposits interfinger laterally with distributary mouth bars, but noted channels are widely separated in wave-dominated deltas. Distributary mouth bars were not identified in this unit within the quadrangle.

South of Steele Butte, a thin sandstone unit occurs above the upper shoreface deposits. It is composed of very fine to fine-grained quartz sand and contains horizontal to slightly inclined bedding with minor trough cross-beds. This is the foreshore facies which forms by wave swash and backswash (Balsley 1982, p. 108). A corresponding vertical sequence with similar interpretations has been described by Balsley (1982) for the Blackhawk Delta in east central Utah and by Hubert and others (1972) for the Cody-Parkman Delta in Wyoming.

Muley Canyon-2. The unit designated as Muley Canyon-2 is composed of up to 25 m of carbonaceous shale and siltstone, coal, and sandstone (fig. 12). It crops out along the west side of the cuestas in the northeastern

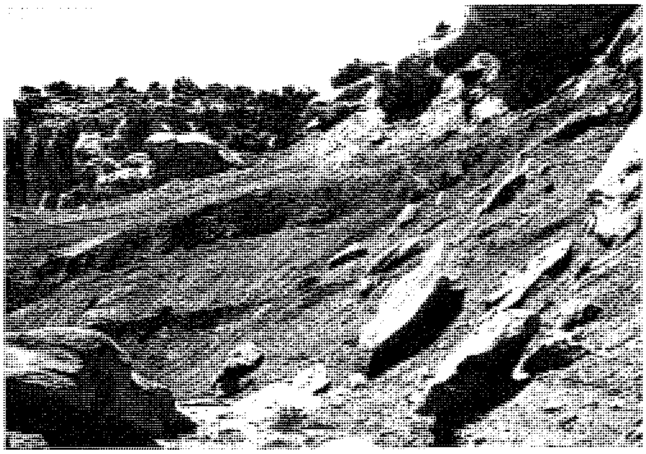


FIGURE 12.—*Muley Canyon-2 unit exposed south of Steele Butte.*

quarter of the quadrangle. In the northwest quarter of the map area, the unit is exposed from Wildcat Mesa almost to Steele Butte.

Twenty-seven coal sections were measured throughout the quadrangle. In most sections a thin carbonaceous shale is at the base, and similar rocks are interbedded throughout the unit. Shale is brownish gray, laminated, and rooted, and it contains plant material.

Coal seams are discontinuous and vary in thickness over short distances (fig. 13). Law (1980, p. 326) stated that the coal is subbituminous A to high volatile C bituminous in rank. It contains sulfur and resin, along the cleats and disseminated throughout the coal, and abundant to sparse vitrain. Cleats are prominent to poorly developed. Coal may be capped by carbonaceous shale, but often siltstone or sandstone are above and grade upward to carbonaceous shale or siltstone. The coal is discussed in more detail below.

Sandstone beds average 2–3 m thick but reach a maximum of 10 m thick and commonly separate the coals. Sandstone is pale yellowish orange and contains 75%–80% very fine to fine-grained quartz with minor chert and calcite cement. Trough cross-beds are present throughout the sandstone.

The Muley Canyon-2 unit forms a slope between more resistant sandstone above and below. The upper contact was mapped at the youngest coal or carbonaceous shale, which is generally capped by cliff-forming sandstone or sometimes by nonresistant mudstone of Muley Canyon-3. The discontinuous and interfingering carbonaceous shale and siltstone, coal, and sandstone of the Muley Canyon-2 unit represent deposition in a delta-plain environment.

The lower part of the unit is a coal zone, with thin shale or sandstone beds and partings. Lower coal seams are more laterally extensive than those in the upper part of the unit. These sediments are similar to lower delta-plain deposits described by Horne (1979, p. 295–300) in eastern Kentucky and southern West Virginia. Lower delta plain sediments are deposited primarily in interdistributary marshes and swamps with minor distributary channel influence.

A sandstone channel in the lower part of the Muley Canyon-2 unit contains bidirectional trough cross-beds that suggest tidal influence (Law 1980, p. 329, 332). These beds may have accumulated in environments like those described by Allen (1970, p. 144, 145), where meandering tidal creeks occur in mangrove swamps of the Niger Delta.

Sediments above the lower delta-plain deposits consist of carbonaceous shale and siltstone, discontinuous coals, and prominent sandstone, or sometimes only sandstone. Sandstone contains abundant trough cross-beds. These rocks are characteristic of upper delta-plain deposits. Horne (1979, p. 296) reported that similar upper delta-plain deposits in eastern Kentucky are dominated by linear, lenticular sandstone channels. Ferm and others (1979, p. 605) described upper delta-plain coals as relatively thick but of limited areal extent, as compared to thin but widespread lower delta-plain coal seams. The coal and carbonaceous shale and siltstone formed in backswamp environments.

Muley Canyon-3. Muley Canyon-3 consists of ledge-and-slope or massive cliff-forming sandstone with minor shale. Thickness of the unit is variable, ranging from 17 m at Blind Trail (fig. 14) to 50 m south of Steele Butte (fig. 15).

Beds of Muley Canyon-3 crop out in the same areas as the lower two units; in the belt of cuestas on the east side of the quadrangle and in the northwest quarter of the map area.

Sandstone in this unit is very pale orange, dark yellowish orange, or pale yellowish brown. It is very fine to fine grained and consists of 75%–80% quartz, 5%–10% chert, 5%–10% calcite cement, and 10% iron oxide. Beds range from very thin to massive with occasional platy, iron-oxide-stained beds.

Several sedimentary features were recognized in the section south of Steele Butte. Ripped-up blocks (up to 0.3 m in diameter) of coal and carbonaceous shale were seen in sandstone at the base of Muley Canyon-3. Similar blocks occur several hundred meters to the south. These blocks resulted as streams deposited the Muley Canyon-3 sandstone and scoured the coal and carbonaceous shale below. Trough cross-beds are abundant and indicate a current flowing N 70° E.

The upper sandstone becomes massive south of Steele Butte (fig. 15). Channel sands occur on erosional surfaces cut on the underlying carbonaceous unit.

A channel fill exposed on the west bank of Sweetwater

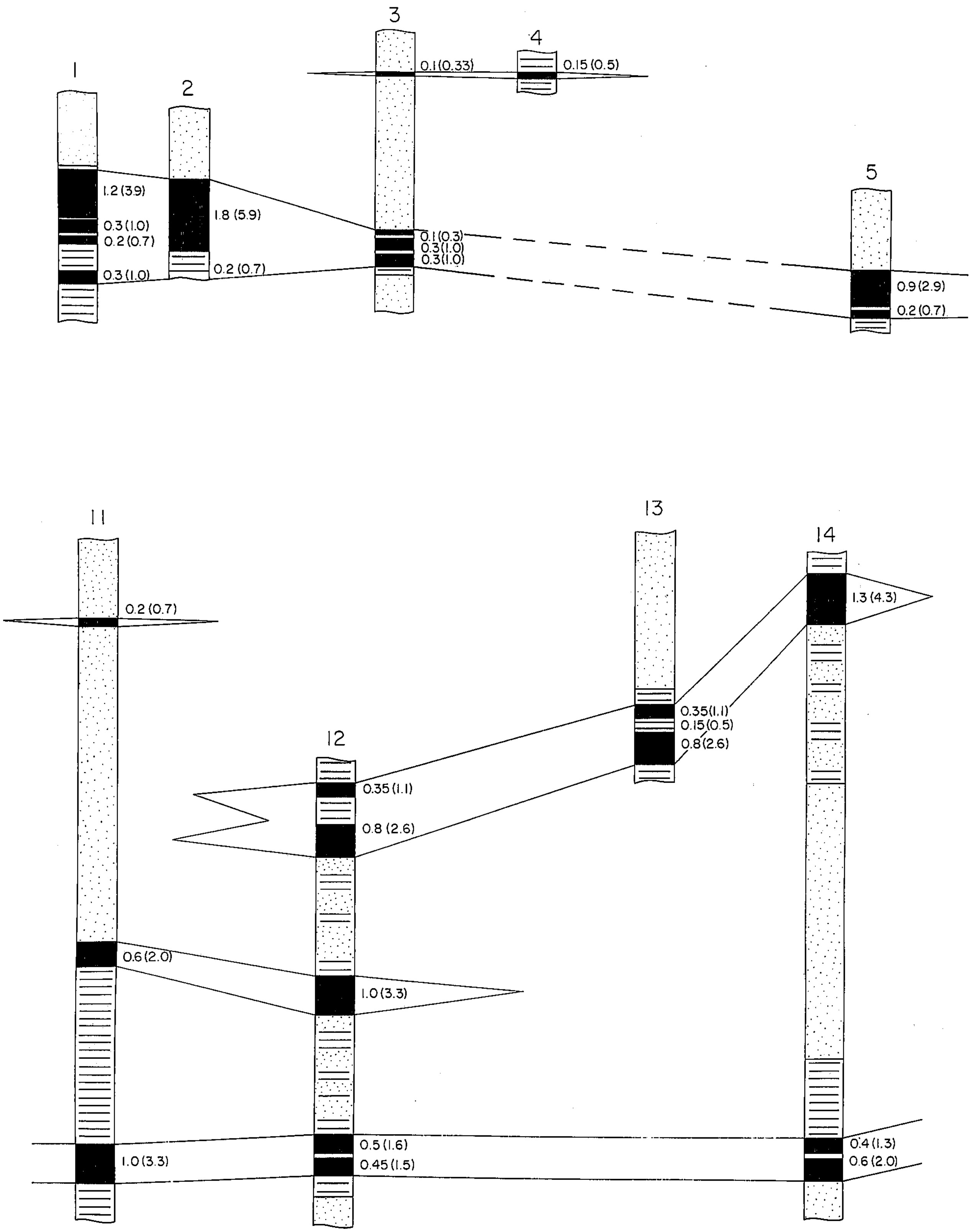
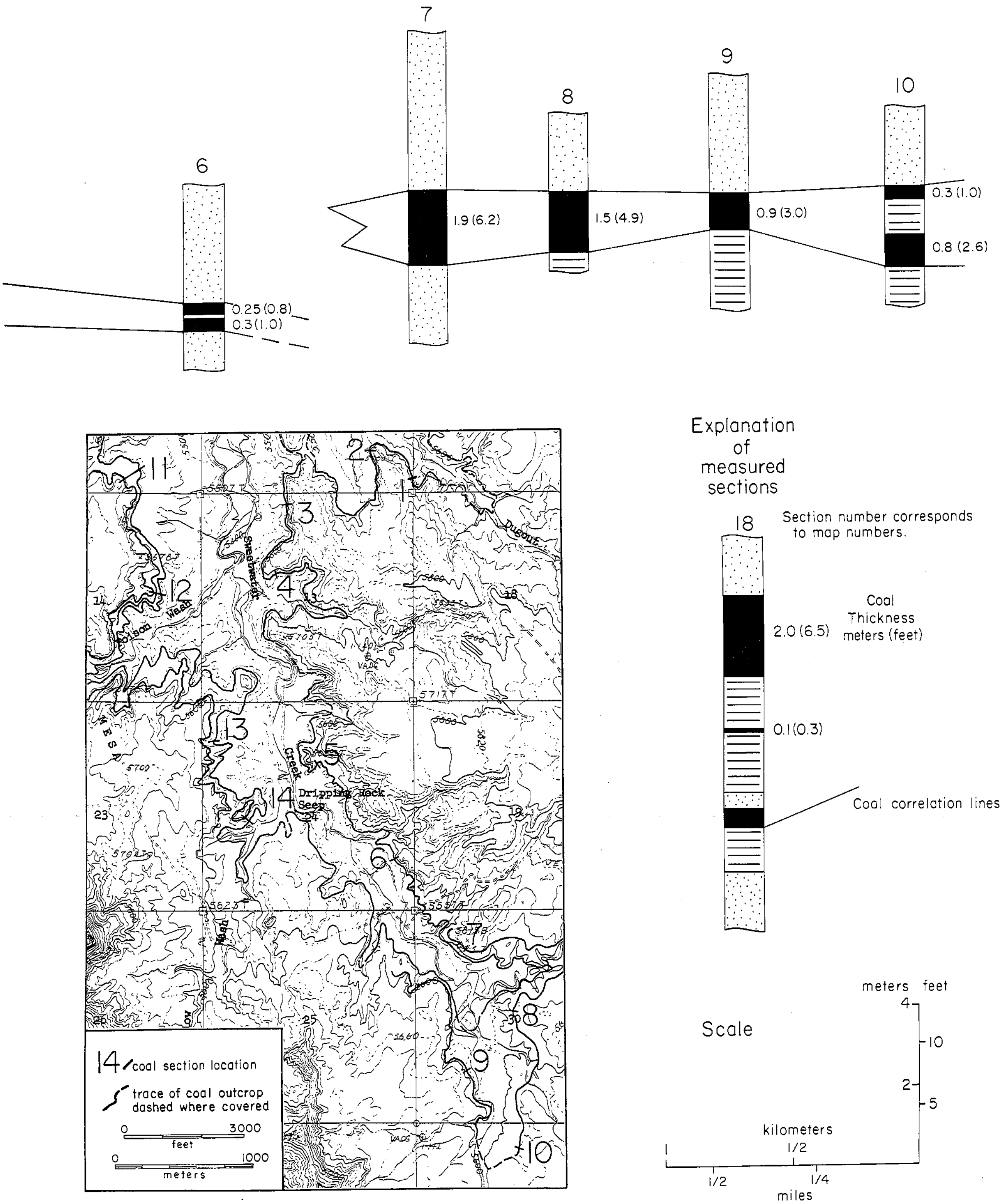


FIGURE 13.—*Diagram of coal sections exposed in the northwest corner of quadrangle showing correlation of coals and discontinuous nature of beds.*



6
0.25 (0.8)
0.3 (1.0)
7
1.9 (6.2)
8
1.5 (4.9)
9
0.9 (3.0)
10
0.3 (1.0)
0.8 (2.6)
Folsom Wash
Sweetwater
Creek
Dripping Rock Seep
Dugout
MESA
14 coal section location
trace of coal outcrop dashed where covered
0 3000 feet
0 1000 meters
Explanation of measured sections
18
Section number corresponds to map numbers.
2.0 (6.5)
Coal Thickness meters (feet)
0.1 (0.3)
Coal correlation lines
Scale
meters feet
4
10
2
5
kilometers
1
1/2
1/2
1/4
miles

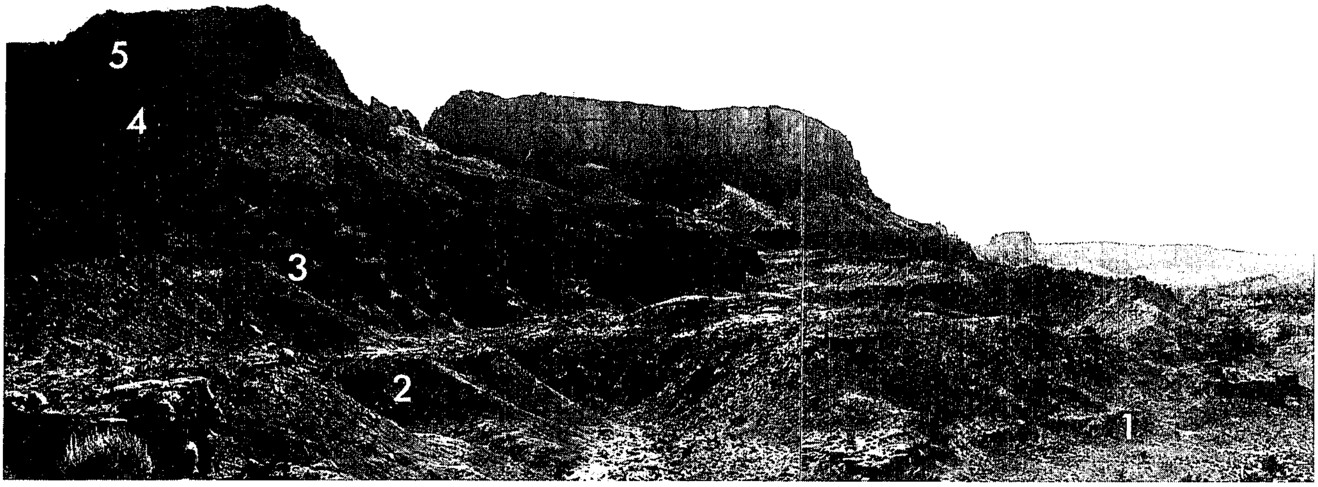


FIGURE 14.—*Muley Canyon-3 (1) unit forms ledge in lower right corner of photograph. Broad slope is composd of Masuk Shale-1 (2), Masuk Shale-2 (3), and Masuk Shale-3 (4), capped by massive Tarantula Mesa Sandstone cliffs (5). View east–southeast of Blind Trail.*

Creek, in the NE ¼, section 25, T. 31 S, R. 8 E, cut into the underlying coals (fig. 16). That channel appears to have an east–west trend.

An interfingering relationship between beds of Muley Canyon-3 and Muley Canyon-2 occurs on the east and west banks of Sweetwater Creek, in section 24, T. 31 S, R. 8 E. In a north–south cross-sectional view, sandstone at the base of Muley Canyon-3 interfingers with, then pinches out to the north within carbonaceous shale and coal of Muley Canyon-2. The upper part of Muley Canyon-3 overlies the carbonaceous zone and is continuous across the area. This appears to have resulted from two coalescing sandstones in the upper unit.

Muley Canyon Sandstone is conformably overlain by Masuk Shale. The upper contact of the Muley Canyon Sandstone Member has been mapped at different stratigraphic horizons by previous authors. Hunt and others (1953, p. 84–85) placed the upper contact of the member at the top of the carbonaceous shale-coal zone and included all overlying sandstone in the Masuk Shale Member (unit 10, fig. 10). Doelling and Graham (1972, p. 110) defined the top of the Muley Canyon Sandstone as the top of all massive sandstone beds above the coal zone (approximately unit 32, fig. 17). Peterson and others (1980, p. 162) and Law (1980, p. 326) placed the contact stratigraphically higher, at the top of the interval of fairly abundant sandstone beds and the base of an interval of sparse sandstone beds and abundant mudstone (approximately unit 33, fig. 17). In this report, the upper contact of the Muley Canyon Sandstone Member was placed stratigraphically lower than Doelling and Graham and Peterson and others mapped it, at the top of a continuous sandstone body that

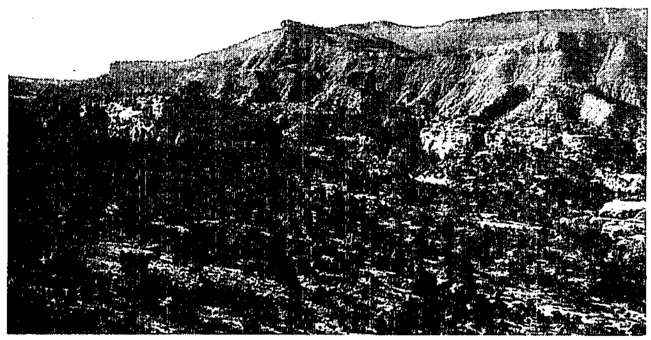


FIGURE 15.—*Muley Canyon-3 unit forms massive cliffs between Steele Butte and Stevens Narrows.*

overlies the middle carbonaceous unit (fig. 10). Above the contact, carbonaceous mudstone and shale are intercalated with abundant, but discontinuous sandstone beds. Throughout the quadrangle, thick, lenticular sandstone bodies similar to the Muley Canyon-3 unit occur in beds mapped as Masuk Member. These younger lenses pinch out laterally in mudstone and shale within the Masuk Shale Member.

Widespread sandstones of the Muley Canyon-3 unit mark a change in sedimentary processes of the region. The prograding deltaic sequence gave way to a destructional deltaic phase, as fluvial-sediment influx decreased, probably in response to abandonment of the main distributary.

The Muley Canyon-3 unit forms a continuous sandstone sheet across the quadrangle and surrounding areas. Lenticular, trough cross-bedded sandstone bodies, often

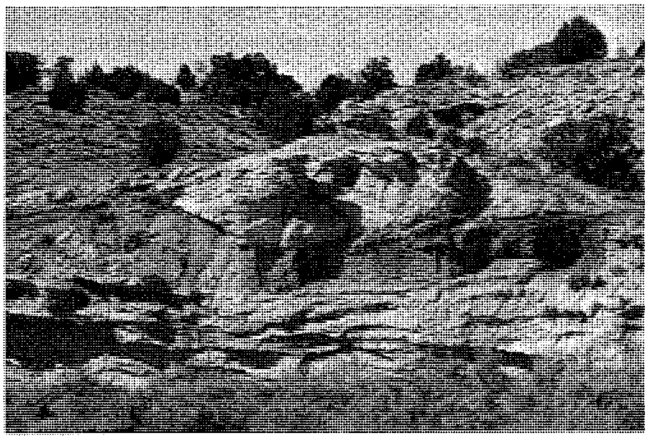


FIGURE 16.—*View west across Sweetwater Creek, in the NW ¼, section 30, T. 31 S, R. 9 E, of fluvial channel of Muley Canyon-3 cut into Muley Canyon-2 coal.*

scoured into the underlying carbonaceous zone, represent distributary channels and distributary mouth bars.

Adjacent to and above the lenticular sandstones are broad sandstone sheets that may be trough cross-bedded, as seen at Stevens Narrows and south of Steele Butte, or flat bedded, as seen along Blind Trail. Broad sands formed during the destructional phase of deltaic sedimentation in which marine processes reworked the sand into thin, widespread deposits. Hubert and others (1972, p. 1663–64) described a similar broad, thin sandstone above delta plain sediments in the Cody-Parkman Delta in Wyoming and presented a similar interpretation. Heward (1981, p. 249) reported thin, widespread sands are typical of destructive deltaic deposits. They result from rapid transgression caused by "limited sediment supply, and compaction and subsidence of the underlying delta lobe."

Masuk Shale Member. The Masuk Shale Member is composed of mudstone, shale, and sandstone, which make it distinctive from the Blue Gate Shale and Tununk Shale Members of the Mancos Shale.

Hunt and others (1953, p. 85) described the Masuk Shale as 183–244 m (600–800 ft) of irregularly bedded, sandy gray shale, sandy carbonaceous shale, and sandstone. Their measured thickness is greater than that reported by subsequent writers because they placed the Muley Canyon Sandstone–Masuk Shale contact stratigraphically lower, at the top of the Muley Canyon carbonaceous zone.

Peterson and others (1980, p. 162) placed the base of the Masuk Shale stratigraphically higher and stated the unit is 186–201 m (612–660 ft) thick, on the basis of several drill holes and measured sections. They collected gastropods, pelecypods, garpike scales, turtle-shell fragments, and crocodilian teeth, which indicate a fresh- to brackish-water environment. Fossils indicate an early Campanian to early late Campanian age for the Masuk Shale.

A section of the Masuk Shale Member, measured near Blind Trail, on the west side of the butte in section 26, T. 31 S, R. 8 E, is 216 m thick (fig. 17), and a section measured on Steele Butte is 204 m thick. Total thickness of the member is consistent; although thicknesses of informal map units are extremely variable over small distances.

The Masuk Shale Member was divided into three informal map units (fig. 17) on the basis of lithologic relations. These units are Masuk Shale-1: interbedded mudstone, discontinuous sandstone, and subordinate shale; Masuk Shale-2: shale with minor sandstone and mudstone; Masuk Shale-3: interbedded sandstone, mudstone, and shale. Masuk Shale-2 of Smith (1983) corresponds approximately to Masuk Shale-2 and 3 of this report.

Masuk Shale-1. Widely exposed from Wildcat Mesa, in the northwest corner, to the southeast corner of the quadrangle is Masuk Shale-1. The rocks are eroded back and form a bench above the Muley Canyon-3 bench. Sandstone beds interfinger laterally with mudstone or shale throughout the map unit. It ranges from 50 m thick at Blind Trail to 53 m thick on Steele Butte.

Sandstone beds are commonly 2–3 m thick, although one bed at Blind Trail measured 16 m thick. Sandstone is yellowish gray to grayish orange and contains 65%–90% very fine to fine-grained quartz, 5%–10% calcite cement, 25%–30% iron oxide, minor silica cement, and gypsum. These rocks form trough cross-bedded lenses and are often channeled into underlying mudstone. Bidirectional trough cross-beds were seen in the sandstone in the NW ¼, section 29, T. 31 S, R. 9 E.

Mudstone comprises approximately half of the lower unit. It varies from olive gray to medium gray and carbonaceous to silty with minor gypsum stringers, coaly material, and macerated plant debris.

Contact with the Masuk Shale-2 unit is gradational and was placed at the base of the horizon where shale begins to predominate over sandstone and mudstone.

Mudstone is the dominant lithology of the unit. Postma (1967, p. 177) reported fine muds are the primary sediments of estuarine environments, forming on shoals and tidal flats that are emergent during low tides. Mud is deposited by clay flocculation in brackish waters in the absence of waves due to a seaward barrier. Lenticular sandstones of the Masuk Shale-1 unit were deposited in fluvial channels of the estuarine environment. Bidirectional trough cross-beds indicate tidal influence on the channels.

Mudstone and sandstone of the Masuk Shale-1 unit represent deposition in an interdeltaic, estuarine environment. Fossils collected by Peterson and others (1980) indicate fresh- to brackish-water environments. These data correspond to the description of the back-barrier estua-

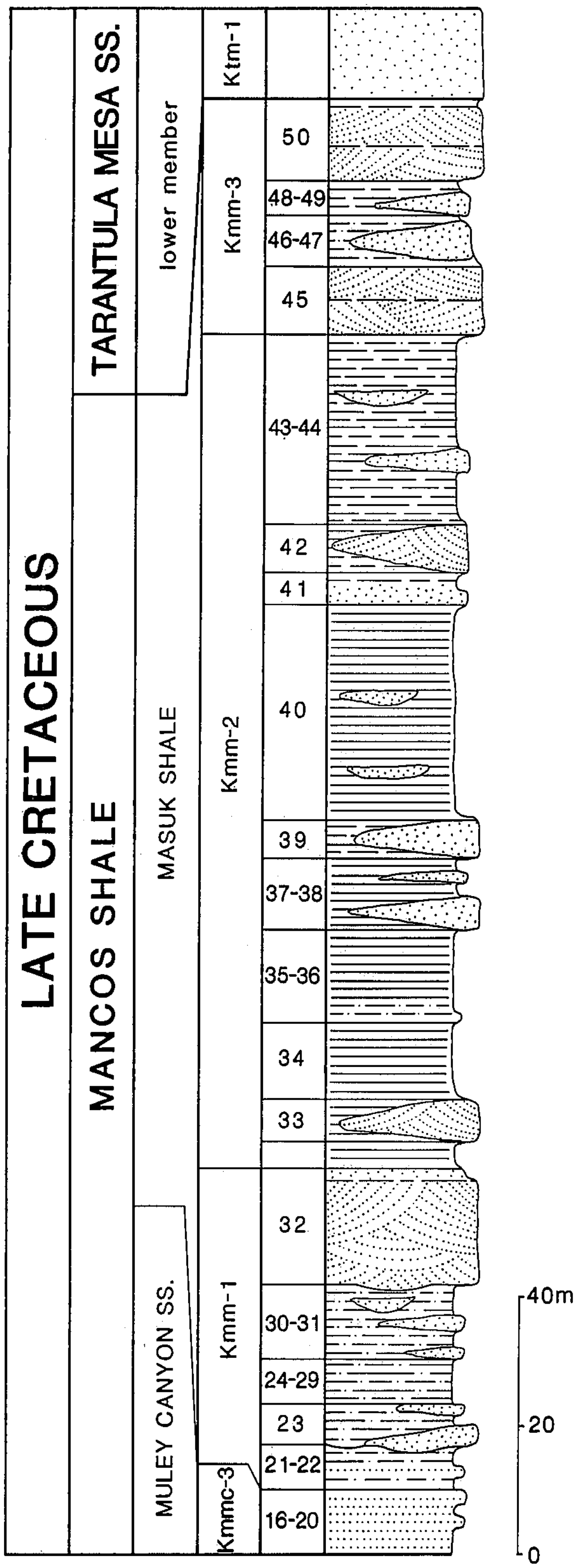


FIGURE 17.—*Stratigraphic column of Masuk Shale section measured east of Blind Trail, showing map unit divisions. Upper contact of the Muley Canyon Sandstone placed at top of unit 32 by Doelling; at top of unit 33 by Law, Peterson.*

rine environment of the Snuggedy Swamp of South Carolina, which includes tidal-flat–salt-marsh complexes to freshwater swamps (Staub and Cohen 1979, p. 501).

Masuk Shale-2. Masuk Shale-2 is exposed along the slope of Tarantula Mesa and nearby buttes. It is extremely variable in thickness, ranging from 66 m at Steele Butte to 128 m near Blind Trail. Almost three-quarters of the unit is olive gray to medium gray, carbonaceous shale. Shale is irregularly laminated and weathers to highly dissected slopes.

Sandstone is pale yellowish orange to pale yellowish brown and contains 75%–85% quartz, 5%–10% calcite cement, and 5%–15% gypsum. Beds range from very thin to massive and form ledges that protect shale slopes.

Contact with the overlying Masuk Shale-3 unit is gradational, and the boundary was placed at the base of the interval where sandstone becomes dominant.

This unit represents continued deposition in the estuarine environment similar to the Masuk Shale-1 unit. Shale has replaced mudstone as the dominant lithology, and the sandstone channels are smaller and less abundant than in the lower unit. These changes indicate a decrease in sand influx into the area.

Masuk Shale-3. Masuk Shale-3 crops out as steep slopes below massive cliffs of Tarantula Mesa Sandstone, along the wall of Tarantula Mesa and nearby buttes.

Pale yellowish orange to yellowish gray sandstone comprises most of the unit. Sandstone contains 85%–95% very fine to fine-grained quartz, cemented by calcite and silica. Beds are medium to massive and pinch out laterally into surrounding mudstone or shale.

Contact with the Tarantula Mesa Sandstone is conformable. The boundary was placed at the top of interbedded sandstone and shale of Masuk Shale-3 and the base of the massive cliff-forming Tarantula Mesa Sandstone.

The Masuk Shale-3 unit represents a continuation of the interdeltaic sedimentation, with an increase of fluvial influence compared to the Masuk Shale-2 unit. These deposits grade into the overlying braided stream deposits of the Tarantula Mesa Sandstone.

Tarantula Mesa Sandstone

The Mesaverde Formation of previous writers is called the Tarantula Mesa Sandstone in this report, following the definition of Smith (1983) for exposures on Tarantula Mesa, in the SE ¼, section 35, T. 32 S, R. 9 E. Peterson and Ryder (1975, p. 185) suggested the formation in the Henry Mountains should be renamed because it correlates with only part of the Mesaverde Group of southwestern Colorado, and it is lithologically different from the type section.

Doelling (1975, p. 48) described the formation as up to 122 m (400 ft) of sandstone with occasional platy sandstone or mudstone partings. Peterson and Ryder (1975, p. 180) dated the Tarantula Mesa Sandstone as early late Campanian on the basis of regional correlations.

The formation caps Tarantula Mesa and several buttes from Tarantula Mesa to Steele Butte. A partial section was measured on the east side of Tarantula Mesa, north of the road, in the southern half of section 23, T. 32 S, R. 9 E. It consists of 85 m of sandstone and conglomeratic sandstone.

The formation was divided into two informal map units (fig. 18), with the boundary between the units placed at the lowest occurrence of conglomeratic sandstone. Where steep cliffs made an area inaccessible, the contact was mapped at the top of the massive cliffs of Tarantula Mesa-1 and the base of the steplike ledges of Tarantula Mesa-2 (fig. 19). On several buttes, where the ledges are not apparent, the formation was mapped as undifferentiated Tarantula Mesa Sandstone.

Tarantula Mesa-1. Seventy meters of pale yellowish orange to light gray sandstone, Tarantula Mesa-1 forms massive cliffs. Pale yellowish orange sandstone at the base is composed of 80%–85% very fine grained quartz, cemented by calcite, with minor iron oxide. Seventy percent of the unit is light gray sandstone composed of 90% very fine grained quartz, with silica cement, and minor chert. Sandstone is medium to very thick bedded, contains trough cross-beds, and is laterally discontinuous (fig. 20). Peterson and others (1980, p. 163) interpreted the lower part of the Tarantula Mesa Sandstone as fluvial deposits.

Tarantula Mesa-2. The upper surface of the Tarantula Mesa Sandstone is erosional across most of the area. A partial section of the upper unit included 15 m of sandstone and conglomeratic sandstone. Conglomeratic sandstone in the lower 4 m is light gray, with chert and quartzite pebbles, in a very fine grained quartz sand matrix. Light gray sandstone similar to the upper part of Tarantula Mesa-1 overlies the conglomeratic sandstone. Tarantula Mesa-2 beds form a series of ledges eroded back from the underlying massive cliffs of the lower unit. This unit represents deposition in a fluvial, braided-stream complex similar to the Tarantula Mesa-1 unit.

"Beds on Tarantula Mesa"

The beds on Tarantula Mesa make up an informal unit first described by Peterson and Ryder (1975, p. 180–81). They occur in the central part of Tarantula Mesa as low mounds of interbedded mudstone and sandstone covered by chert gravel.

A section measured by Smith (1983) consists of 18 m of interbedded silty, carbonaceous, bentonitic mudstone and very fine to fine-grained, yellowish gray sandstone. The unit forms a ledge-and-slope topography.

Peterson and Ryder (1975, p. 180) stated that no age-diagnostic fossils have been found but suggested the unit is early late Campanian in age on the basis of regional correlation. Contact with the Tarantula Mesa Sandstone is conformable, but usually is covered by gravel.

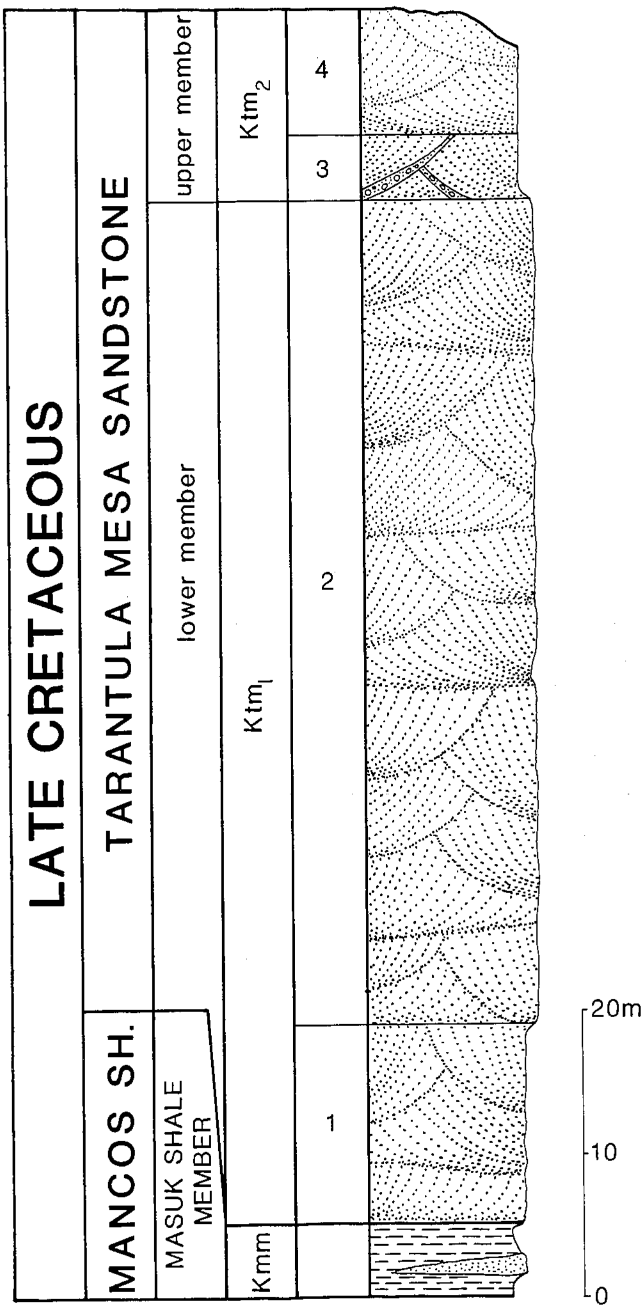


FIGURE 18.—*Stratigraphic column of Tarantula Mesa Sandstone measured on the east side of Tarantula Mesa, showing map unit divisions.*

FIGURE 19.—*Massive cliffs of Tarantula Mesa-1 unit are overlain by steplike ledges of Tarantula Mesa-2 unit.*

FIGURE 20.—*Trough cross-bedded, sandstone lenses in Tarantula Mesa Sandstone.*

TERTIARY SYSTEM

Diorite Porphyry Intrusions

Armstrong (1969, p. 2984) reported the Henry Mountains igneous intrusions to be 44 to 48 m.y. old on the basis of K-Ar dating of the diorite porphyry (whole rock analyses) and hornblende. Recent radiometric dates for similar laccolithic bodies on the Colorado Plateau, such as the Ute Mountains, range from 20–25 m.y. (Rowley and others 1978, p. 51–55) to 64–72 m.y. (Cunningham and others 1977, p. 5) and suggest possible discrepancy in dating the Henry Mountains intrusions.

Diorite porphyry intrusions are exposed in four locations in the northeast corner of the quadrangle. Intrusions penetrated the stratigraphic units up into the Tununk Shale Member and are bordered by normal faults, low-angle reverse faults, and folded, baked country rocks. The largest exposed igneous body is located south of Dugout Creek, in the NE ¼, section 26, T. 31 S, R. 9 E. It is approximately 350 m long by 150 m wide. A well on Apple Brush Flat, in the NW ¼, section 22, T. 31 S, R. 9 E, drilled through 60 m of igneous rock. Additional igneous intrusions and thicker bodies probably occur closer to the stocklike intrusion of North Summit Ridge, approximately 5.6 km east of the quadrangle (Affleck and Hunt 1980, p. 111, 112).

Intrusive bodies associated with the Mount Ellen stock are diorite porphyry with phenocrysts of oligoclase, hornblende, and magnetite (Hunt and others 1953, p. 152). Igneous intrusions weather to cliffs and ledges.

QUATERNARY SYSTEM

Five types of Quaternary deposits were mapped in the Steele Butte Quadrangle. They are pediment gravel, alluvial terrace gravel, eolian sand and loess, colluvium, and stream alluvium.

Pediment Gravel

A veneer of gravel occurs above pediments in several isolated outcrops in the eastern half of the quadrangle. Gravel caps a surface cut across Masuk Shale and Muley Canyon Sandstone north of Dry Wash, in sections 8, 9, and 10, T. 31 S, R. 9 E. East of Mud Spring, in sections 14 and 23 and the SE ¼, section 15, T. 31 S, R. 9 E, the gravel rests across the Ferron Sandstone, Tununk Shale, and Dakota Sandstone. Pediment gravel caps the Muley Canyon Sandstone and Blue Gate Shale south of Sage Flat, in sections 1, 2, and 11, T. 32 S, R. 9 E.

Pediment gravel is composed of cobbles and boulders of diorite porphyry, from the Mount Ellen intrusions, in a matrix of very fine to fine-grained, light brown sand.

Gravel deposits, with an eastern source from the Mount Ellen intrusions, cap beheaded pediments. They are topographically higher than surrounding alluvial terrace gravels, having been deposited on a former cut surface. Erosion of the surrounding area cut through and left the isolated high remnants. Deposition of alluvial gravel continued across the lower level.

Alluvial Terrace Gravel

Alluvial terrace gravel blankets most of the northeastern third of the quadrangle and forms isolated deposits in the south central quarter. Thickness ranges from over 15 m near the foot of Mount Ellen to a thin veneer along the western border of the gravel cover.

Deposits formed where lobes of alluvium from Cedar Creek, Dugout Creek, and South Creek coalesced. Isolated gravel terraces in the south were deposited by the stream that flowed through Stevens Narrows. Several of the southern deposits contain debris derived from the Masuk Shale and Tarantula Mesa Sandstone cliffs on Tarantula Mesa and differ from deposits elsewhere that are dominated by igneous debris.

Stream Alluvium

After deposition of the alluvial gravel, streams in the area again entrenched. Alluvium of fine sand to cobbles in diorite porphyry has accumulated in and along major creeks and washes in the area.

Eolian Sand and Loess

Several isolated areas of eolian deposits were mapped on Tarantula Mesa. These sediments are composed of pale red silt to medium-grained sand. They appear as broad, flat sandy areas with limited vegetation.

Colluvium

Colluvium has developed at the base of several steep slopes of igneous and sedimentary rocks in the northeast corner of the quadrangle. These deposits are unconsolidated debris composed of angular blocks of cobbles and boulders with lesser fine material.

STRUCTURAL GEOLOGY

GENERAL STATEMENT

The Steele Butte Quadrangle lies within the Henry Mountains structural basin, which is a north–south-trending asymmetric syncline with a shallow east limb and steep west limb. The nearby Waterpocket Fold of the Capitol Reef area forms the west limb of the basin. Hunt (1953, p. 90) suggested the Henry Mountains structural basin formed between Late Cretaceous and early Eocene, and igneous bodies intruded the east limb of the syncline during Eocene time (Armstrong 1969, p. 2084).

Two major structural types are recognized in the quadrangle: (1) broad, shallow features related to the Henry Mountains basin and (2) large- to small-scale folds and faults associated with igneous intrusions. Quaternary toreva-block slides are minor structural features in the quadrangle.

A structural contour map (fig. 21), on the top of the Muley Canyon-1 sandstone, shows the gentle character of the Henry Mountains syncline and the somewhat more abrupt folds associated with igneous intrusions. Faults have only minor displacements and are not apparent on the contour map because of the interval.

HENRY MOUNTAINS STRUCTURAL BASIN

The major structure of the basin is the Henry Mountains syncline. Axis of the syncline extends north–south near the western margin of the quadrangle and plunges southward under Tarantula Mesa. Beds in the western half of the quadrangle, which are unaffected by the intrusions, dip gently up to 4° into the syncline.

STRUCTURES ASSOCIATED WITH INTRUSIVE BODIES

Igneous intrusions associated with the Mount Ellen stock have deformed sedimentary rocks in the eastern half of the quadrangle. They show regional upwarping and dip 7°–10° W near the center of the quadrangle but 15°–25° W along the Muley Creek Sandstone cuesta and areas to the east (fig. 21).

Hunt and others (1953, p. 90) described laccoliths in the Henry Mountains area as tongue-shaped intrusions that deformed the overlying sedimentary rocks into anticlinal noses that opened toward the stock. The structural contour map shows several west-plunging anticlines which correspond with projections of laccolithic bodies to the east.

Igneous intrusions have upwarped strata from the Entrada Sandstone through the Ferron Sandstone in the northeast corner of the quadrangle, from 1.6 km south of Dugout Creek to the middle of section 11, T. 31 S, R. 9 E.

Several normal faults and one low-angle reverse fault were mapped in the area. They resulted from upwarp around the laccolithic bodies. Normal faults are generally traceable for less than 2 km and have average vertical displacements of 15–25 m. Maximum displacement of 60–75 m was observed on one fault in the NW ¼, section 14, T. 31 S, R. 9 E. The low-angle reverse fault in section 25, T. 31 S, R. 9 E, is within the Salt Wash Member and has approximately 40 m displacement.

TOREVA-BLOCK SLIDES

Three toreva-block slides were mapped in the quadrangle. Two blocks, approximately 250 m wide by 210 m high, occur near the top of the cuesta northeast of Stevens Narrows, in the center of section 14, T. 32 S, R. 9 E. The blocks are Blue Gate Shale capped by Muley Canyon Sandstone and have slid 20–35 m downslope. A similar toreva block composed of the upper member of the Cedar Mountain Formation capped by Dakota Sandstone was mapped north of Dugout Creek, in the west central part of section 23, T. 31 S, R. 9 E. The block is approximately 150 m wide by 50 m high and has slid 10–15 m downslope.

ECONOMIC GEOLOGY

COAL

Coal is a major potential economic resource in the Henry Mountains basin. It occurs widely in the Muley Canyon and Ferron Members and locally in the Dakota Sandstone (Doelling and Graham 1972, p. 117).

Coal in the Muley Canyon Member is exposed in the Steele Butte Quadrangle, but Ferron coal is covered by thick gravel deposits near Dugout Creek and increasingly

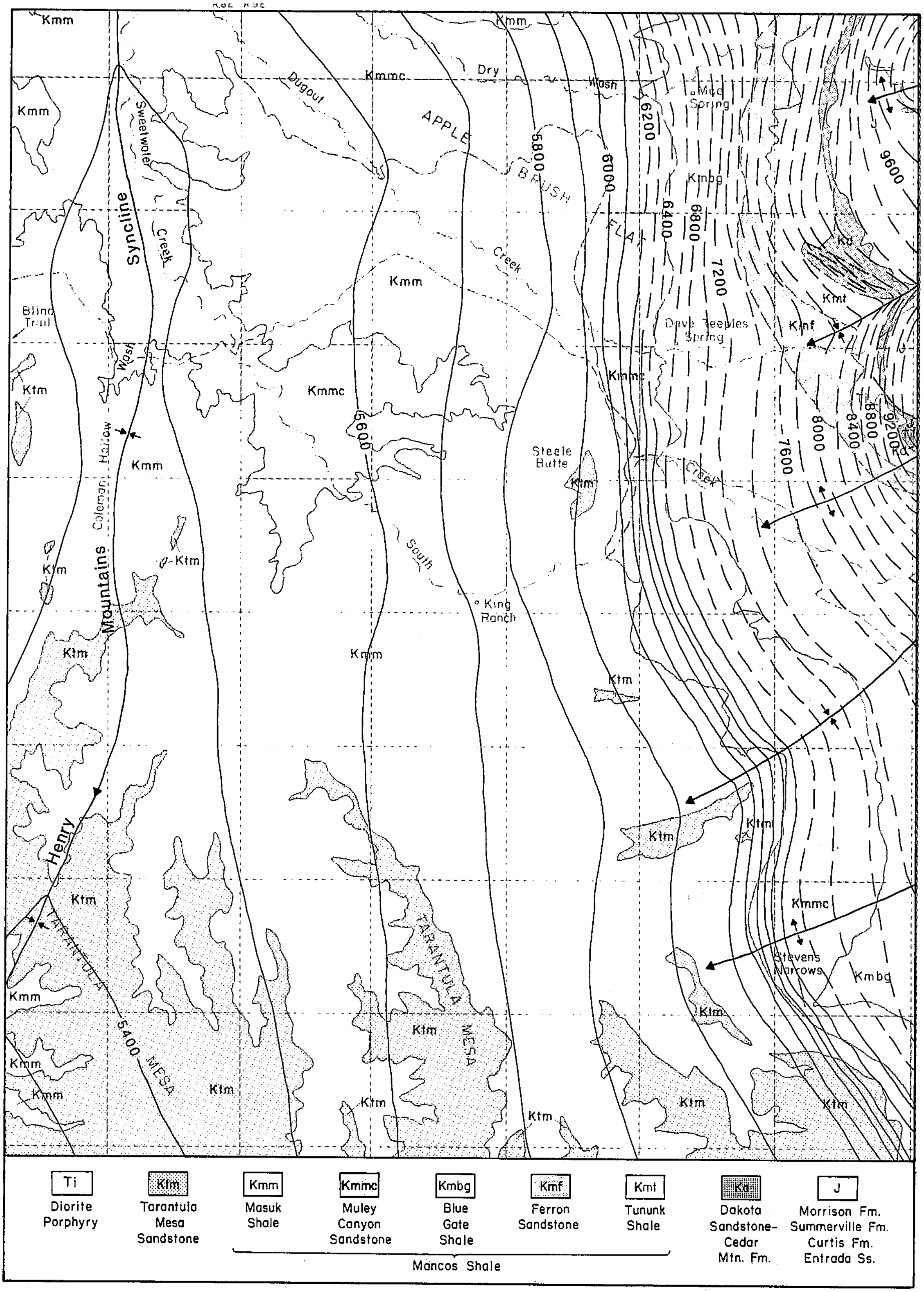


FIGURE 21.—*Structural contour map superimposed on a simplified bedrock geologic map. Contours drawn on top of Muley Canyon-1 unit. Contour interval is 100 feet west of 6,400-foot contour; 200-foot interval east of 6,400-foot contour.*

thick overburden to the west as beds dip into the Henry Mountains syncline. No coal was observed in the Dakota Sandstone in the quadrangle, but coal does occur in beds exposed along the Waterpocket Fold, to the west.

Muley Canyon coal is exposed along the banks of Sweetwater Creek and Dugout Creek, in the northwest corner of the map area and in the belt of cuestas on the east side of the quadrangle. Along the cuestas, the coal thickens from Dry Wash to South Creek; then, 2 km south of South Creek to the corner of the quadrangle, the coal is exposed as discontinuous outcrops.

Coal outcrops in the northwest quarter of the quadrangle contain 1–4 discontinuous seams that total 0.3–3.0 m thick (fig. 13). The maximum coal reported in the northwest part of the area is 6.5 m in a test well drilled east of Blind Trail, in the SW ¼, section 23, T. 31 S, R. 8 E.

In the northeastern quarter of the quadrangle, coal increases from 0.2 m thick at Dry Wash to 2.1 m thick in South Creek. South of Dry Wash, in the NW ¼, section 16, T. 31 S, R. 9 E, 0.2 m of coal is overlain by sandstone. Near Dave Teeples Spring, 0.4 m of coal at the base is overlain by sandstone capped by carbonaceous shale and siltstone. Along South Creek, carbonaceous shale and siltstone grade to 1.2 m of coal which overlies 10.5 m of sandstone with 0.9 m of coal at the base.

Coal is exposed in a belt of discontinuous outcrops from 2 km south of South Creek, in the NE ¼, section 33, T. 31 S, R. 9 E, to the southeast corner of the quadrangle. Hunt and others (1953, p. 84) and Doelling and Graham (1972, p. 117) noted the discontinuous coal beds south of Steele Butte. Law (1980, p. 329) reported southward thinning of the coal in outcrops immediately west of the quadrangle, similar to thinning of the coal reported in outcrops in the southeastern corner of the quadrangle. A well located in the NE ¼, NE ¼, section 17, T. 32 S, R. 9 E, between the eastern and western outcrops, drilled through the Muley Canyon Sandstone but penetrated no coal. Combined surface and subsurface evidence indicates an area of thin to discontinuous coal in the southern half of the quadrangle (fig. 22).

A coal isopach map (fig. 22) was constructed from 27 measured coal sections, plus data from previous reports (Doelling and Graham 1972, Law 1980). The map shows three areas of coal accumulation greater than 1.21 m (4 ft) thick. These are (1) from Wildcat Mesa to Coleman Hollow Wash, in the northern half of section 2, T. 32 S, R. 8 E, and northeast to Dugout Creek, in the SW ¼, section 7, T. 31 S, R. 9 E; (2) southwest from Dry Wash, NW ¼, section 9, T. 31 S, R. 9 E, across Apple Brush Flat and South Creek to Tarantula Mesa; and (3) in the vicinity of Steele Butte and King Ranch. The map also shows the area of discontinuous coal in the southern one-third of the quadrangle.

Several features are associated with the discontinuous coal outcrops south of South Creek.

1. Two coal seams are present in the northern outcrops, but only the lower coal continues southward. Farther south the lower coal is also cut out.
2. South of South Creek, large blocks (up to 0.3 m in diameter) of ripped-up carbonaceous shale and coal occur in sandstone above the lower coal. Abundant trough cross-beds in the Muley Canyon-3 sandstone indicate they were deposited by an eastward-flowing stream.
3. The Muley Canyon-3 sandstone is considerably thicker (50 m) where the coal is cut out, than at Stevens Narrows to the south (24 m) or to the northwest at Blind Trail (17 m).

These data indicate that thinning and removal of coal are due to erosion by streams that deposited the massive Muley Canyon-3 sandstone.

Law (1980, p. 329) previously attributed the thin coal to limited accumulation on the crest of the Teasdale Anticline during Cretaceous time. He suggested that the southeast-trending anticline formed in Late Jurassic time and extended eastward through the quadrangle as a structural high feature limiting coal swamp development. However, isopach and depositional patterns have strong northeast trends indicating major northeast-flowing streams were the major control on deposition and erosion of the coals.

Muley Canyon coal has thin total overburden plus interburden across much of the quadrangle. Cover is generally less than 45 m (150 ft) thick, with small areas up to 60 m (200 ft) thick. The area of thin overburden extends north from near King Ranch to the northern boundary of the quadrangle and is bounded on the south and southwest by Tarantula Mesa and on the east by Steele Butte and the coal outcrop.

Doelling (1975, p. 84, table 18) reported 75.5 million short tons of estimated and inferred reserves of Muley Canyon coal in the Stevens Mesa and Steele Butte Quadrangles. Coal is subbituminous A to high-volatile C bituminous and contains 1.0% sulfur and 11,300 Btu/lb (Hatch and others 1980, p. 339; Doelling and Graham 1972, p. 164, table 8). One mine was developed in the Muley Canyon coal at Sweetwater Creek and another along Dugout Creek in the 1940s (Doelling and Graham 1972, p. 165). The mines are now abandoned, but their entries are located in the NW ¼, NW ¼, section 30, near Sweetwater Creek, and in the SW ¼, SW ¼, section 7, T. 31 S, R. 8 E, near Dugout Creek.

Coal deposits in the northern half of the Steele Butte Quadrangle are suitable for strip mining because of the combination of appreciable coal and less than 45 m (150 ft) of overburden across much of the area. One deterrent

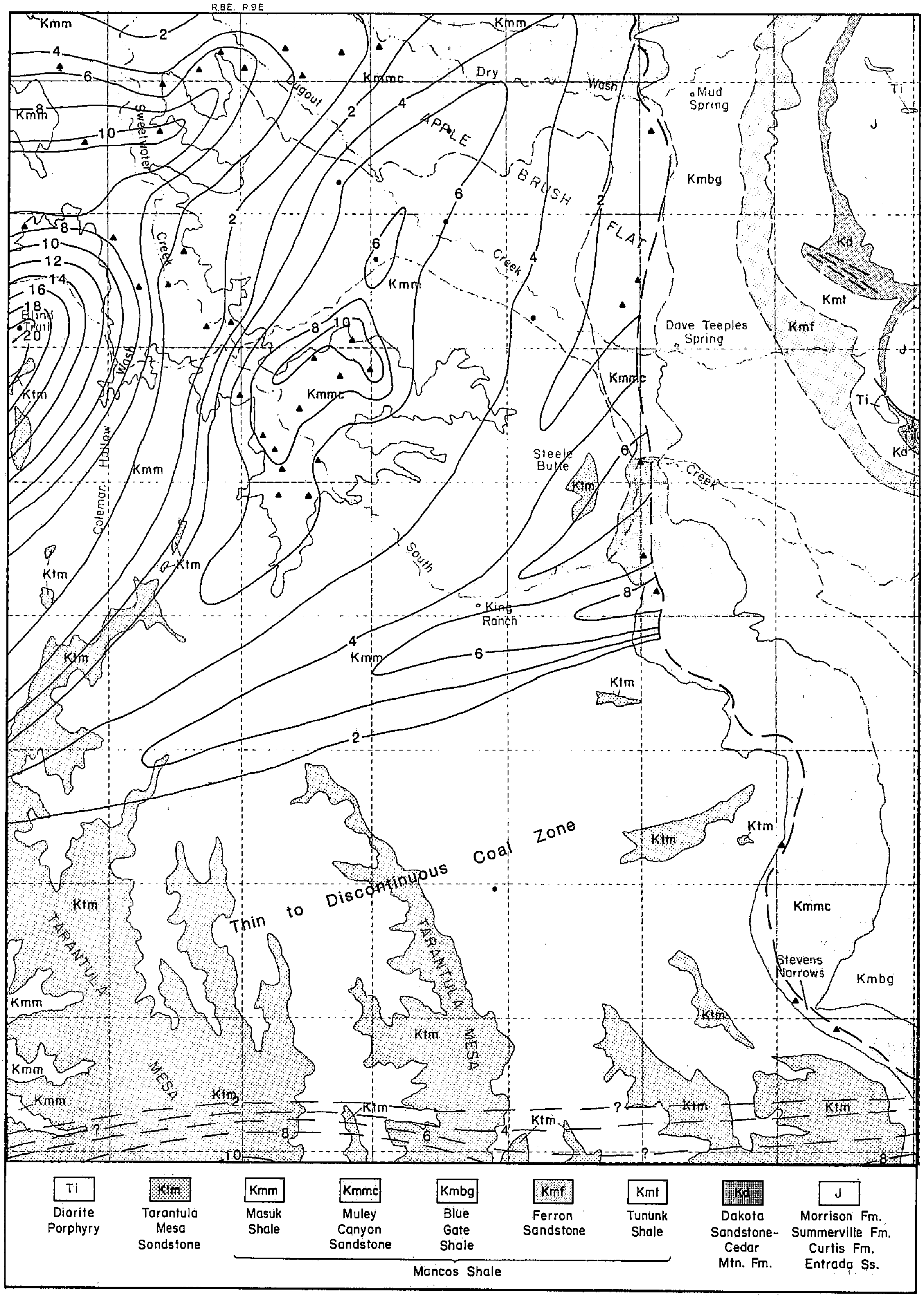


FIGURE 22.—*Isopach map of total coal in the Muley Canyon Sandstone superimposed on a simplified bedrock geologic map. Contour interval is 2 feet. Data points are triangles = measured sections, dots = drilled holes.*

to mining, however, is the remoteness of the area when compared to coalfields in Emery and Carbon Counties.

PETROLEUM

The Henry Mountains region has not produced oil and gas yet. Irwin and others (1980, p. 358) discussed the hydrocarbon potential of the area and reported that several units, including the Moenkopi, Kaibab, White Rim, Honaker Trail, and Paradox Formations, have had live oil shows in tests around the basin but have not produced within the basin.

A well by Webb Resources on Apple Brush Flat drilled through the White Rim Sandstone and produced fresh water from that formation. Another Webb Resources well on Cave Flat, approximately 9 km southeast of the quadrangle, also drilled through the White Rim Sandstone and produced fresh water. Recently, Exxon abandoned a well in the NW ¼, SE ¼, section 24, T. 31 S, R. 9 E, after drilling 2,454 m.

CONSTRUCTION MATERIALS

Roads that cross Mancos Shale become almost impassable during wet weather. Quaternary terrace gravel deposits, in the northeast third of the quadrangle, are a source of road metal. Deposits composed of diorite porphyry pebbles to boulders thin to the west. Most promising deposits are those on Apple Brush Flat near the foot of the mountain. Gravel was excavated on Apple Brush Flat, in the NE ¼, section 22, T. 31 S, R. 9 E, and provided material for construction of large sections of road from Sandy Creek to the Exxon well site.

WATER RESOURCES

Water is a limited resource in the Steele Butte Quadrangle. Dugout Creek, South Creek, and Sweetwater Creek are the only regularly flowing streams, but they may dry up in sections of their courses in the late summer months. They are fed from springs and melting snow on Mount Ellen.

Only two significant springs are present in the quadrangle. Dave Teeples Spring, in the SW ¼, section 22, T. 31 S, R. 9 E, is a good supply of water, but water rights are privately owned. Mud Spring, in the NE ¼, NW ¼, section 15, T. 31 S, R. 9 E, is a minor, undependable source of water. Several seeps in the northern half of the quadrangle provide negligible amounts of water.

SUMMARY

Sedimentary rocks exposed in the quadrangle were deposited in a variety of environments. The Jurassic Entrada Sandstone, Curtis Formation, Summerville Formation, and Morrison Formation represent interdeltaic-coastal, shallow-marine, tidal-flat, fluvial, lacustrine, and ash-fall deposits. The Lower Cretaceous Buckhorn Conglomerate was formed by fluvial and eolian processes. Above the Buckhorn Conglomerate, the upper member of the Cedar Mountain Formation is composed of reworked Brushy Basin shales deposited in local basins.

Upper Cretaceous Dakota Sandstone and Mancos Shale document a series of marine transgressions and regressions. The Dakota Sandstone consists of fluvial deposits overlain by beach and shallow-marine sediments. Continued transgression of the sea deposited marine shale of the Tununk Shale Member. The prograding "Notom" Delta (Hill 1982) caused the sea to withdraw from the area and deposited Ferron Sandstone sediments. This regression was followed by a destructive deltaic phase and associated marine transgression in which Blue Gate Shale deposits similar to the Tununk Shale were formed. Prodelta shale and transitional deltaic shale and sandstone comprise the upper half of the Blue Gate Shale and mark another regression of the sea in response to progradation of the Muley Canyon Sandstone delta. The lower two-thirds of the Muley Canyon Sandstone is composed of delta-front sandstones overlain by delta-plain sediments. Fluvial sandstones and transgressive sheet sandstones that form the upper part of the Muley Canyon Sandstone mark the end of the constructive deltaic phase. The Masuk Shale was deposited in an interdeltaic-estuarine environment as the main delta lobe shifted away from the area. The Tarantula Mesa Sandstone is composed of fluvial, braided-stream deposits and indicate the end of the transgressive-regressive sequence.

Following deposition of the strata, deformation created the Henry Mountains syncline during Late Cretaceous and early Tertiary. Subsequent to inception of the syncline, igneous activity produced the Henry Mountains intrusions. The structure contour map (fig. 21) displays features formed during these events.

Uplift and erosion have exposed the Jurassic, Cretaceous, and Tertiary rocks within the quadrangle and produced five types of Quaternary deposits.

The processes which produced the Muley Canyon Sandstone influenced coal distribution in the area, with resulting economical accumulations of coal suitable for strip mining. Figure 22 is a total coal isopach of the quadrangle.

The appendix for this paper, manuscript pages 47–66, are on file at the Department of Geology, Brigham Young University, Provo, Utah 84602, where a copy may be obtained.

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