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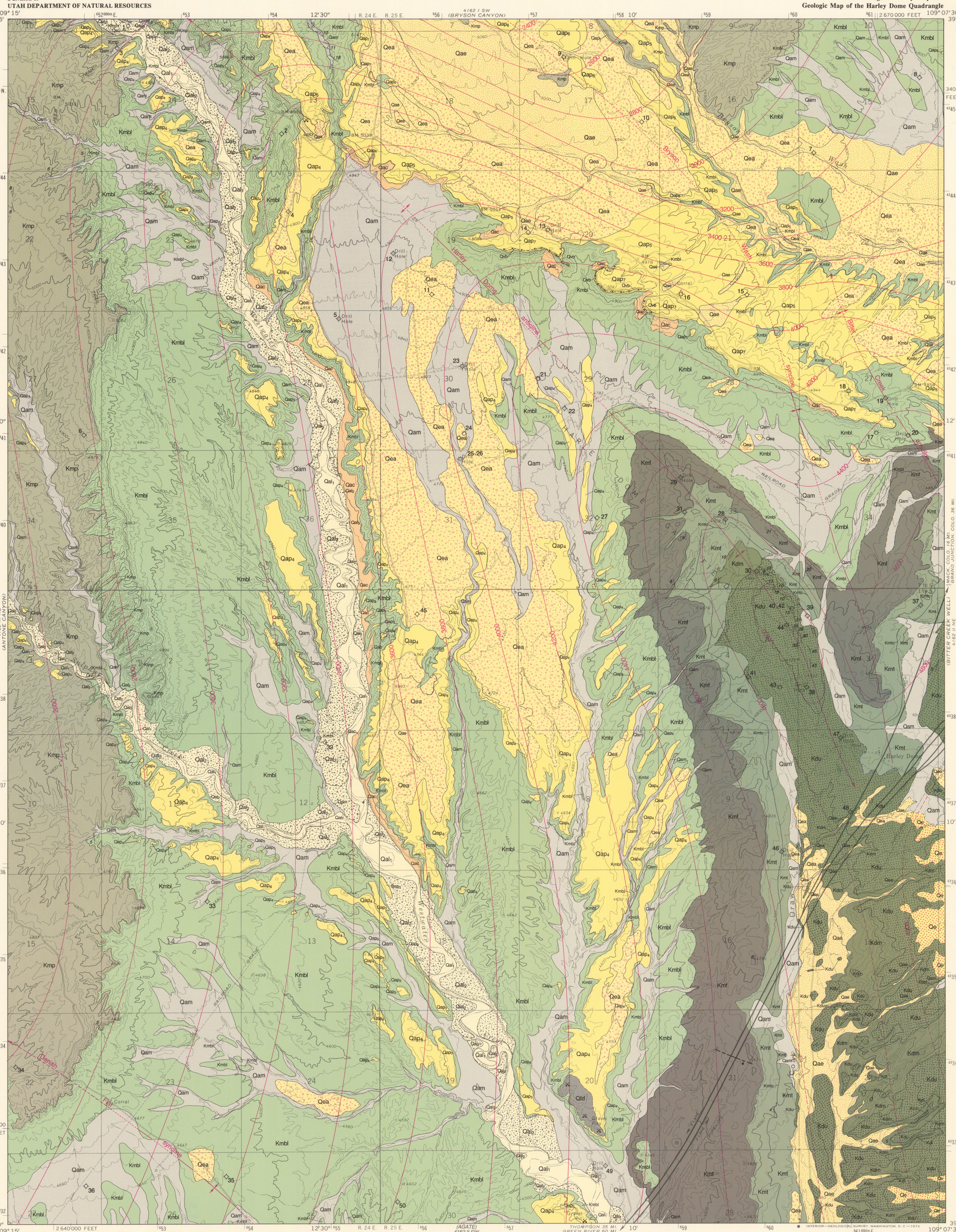
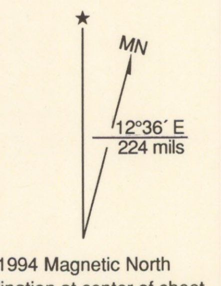
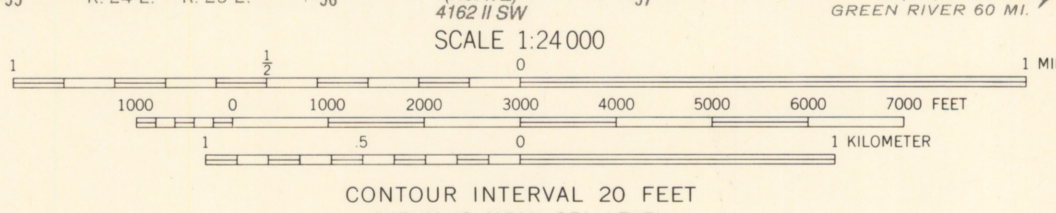


Base map from the U. S. Geological Survey
Harley Dome 7.5' Quadrangle, 1970



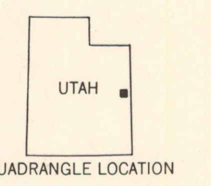
12°36' E
224 mils

1994 Magnetic North
Declination at center of sheet



SCALE 1:24 000

CONTOUR INTERVAL 20 FEET
DATUM IS MEAN SEA LEVEL



UTAH

QUADRANGLE LOCATION

Field work completed 1989 - 1991
Lori J. Douglas, Cartographer

GEOLOGIC MAP OF THE HARLEY DOME QUADRANGLE, GRAND COUNTY, UTAH

by

Grant C. Willis

1994

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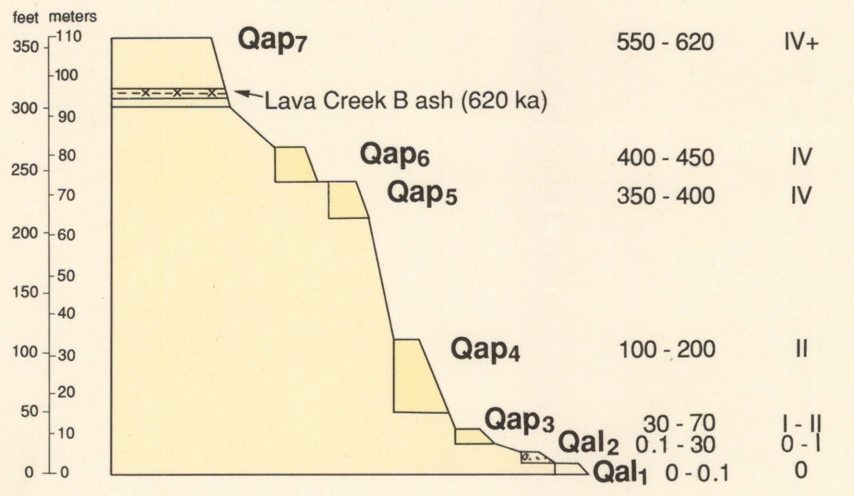
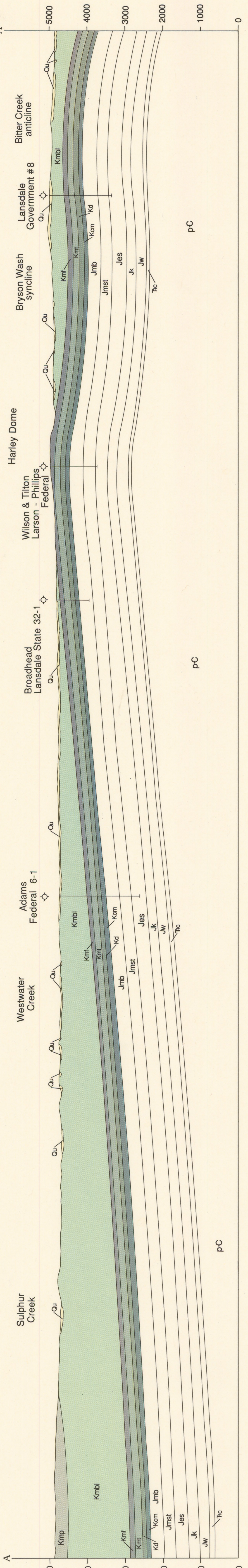


Correlation of Pediment and Terrace-mantle Deposits

Diagram of major alluvial units, relative elevation above Westwater Creek, and estimated age. Ages are estimated using calculated rates of pedogenic (soil) carbonate accumulation and local downcutting of the Colorado River and its tributaries. The 620,000-year-old Lava Creek B volcanic ash, exposed near the base of the highest and oldest pediment-mantle deposits, is the datum for calculations. See discussion in the text. Mapped deposits without number subscripts generally have a wider age range.



DESCRIPTION OF MAP UNITS

Qu Undivided Quaternary deposits - *Shown in cross section only.*

Qfd Fill and disturbed areas - *Moderately to poorly sorted gravel and fill; includes deposits of waste materials from screening and washing of gravel and adjacent excavated areas. (Locally thick highway and railroad fill and small dams built across ephemeral washes were not mapped separately).*

Qe Eolian deposits - *Well- to very well-sorted sand and silt, and minor loess; blankets benches of the Dakota Sandstone in areas mostly free of alluvial deposits; has a distinctive reddish-orange color imparted by source materials (Jurassic and Triassic "red rock" formations exposed to the southwest); ranges from 0 to 40 feet (0 - 12 m) thick.*

Qae Mixed alluvial and eolian deposits - *Moderately to well-sorted clay to boulder-sized material; dominated by alluvial processes; eolian component varies from locally absent to moderate; intermediate between, and gradational with, Qal_1, Qal_2, and Qea; similar to Qam but has more sand, pebbles, and boulders, and less clay and silt; 0 to 30 feet (0 - 9 m) thick.*

Qea Mixed eolian and alluvial deposits - *Moderately well- to very well-sorted, sand, silt, and loess, with sparse pebbles and cobbles; eolian component generally more abundant than alluvial component; has a distinctive reddish-orange color imparted by eolian source (Mesozoic "red rock" formations exposed to the southwest); present on older surfaces in areas of limited alluvial influence; ranges from 0 to 10 feet (0 - 3 m) thick; gradational with other Quaternary surficial deposits.*

Qac Mixed alluvial and colluvial deposits - *Poorly to moderately sorted, clay- to boulder-size material deposited on and at the base of slopes, especially near the base of dissected pediments; many smaller deposits are not mapped separately; 0 to 20 feet (0 - 6 m) thick; gradational with other Quaternary surficial deposits.*

Alluvial deposits are common on terraces and pediments ranging from present drainage bottoms to about 360 feet (110 m) above adjacent drainages. These deposits have been lumped into a limited number of units to facilitate mapping. Numbers denote relative ages and heights above adjacent drainages; level 1 is the youngest (active drainages) and level 7 is the oldest and highest. See the discussion in the text.

Qam Alluvial mud and sheet-wash deposits - *Moderately well-sorted silt, clay, and some sand; locally with minor coarse clastic or eolian deposits; covers broad surfaces with poorly developed drainages; derived primarily from the Mancos Shale; generally equivalent in age and gradational with units Qal_1, Qal_2, Qae, and Qea; ranges from 0 to 20 feet (0 - 6 m) thick.*

Qal_1 Younger alluvial deposits - *Poorly to moderately sorted boulders, cobbles, sand, silt, and clay along major stream channels; present up to 10 feet (3 m) above active drainages; includes deposits of Qal_2 where undifferentiated or too small to map separately; gradational with other Quaternary surficial deposits; ranges from 0 to about 20 feet (0 - 6 m) thick.*

Qal_2 Older alluvial deposits- *Poorly to moderately sorted boulders, cobbles, sand, silt, and clay that have been incised by downcutting of washes; similar to Qal_1 but upper surface of deposit is 10 to 30 feet (3 - 9 m) above adjacent drainages; locally, materials are being deposited on these surfaces from small side washes and adjacent slopes; gradational with other Quaternary surficial deposits; differentiated only near larger drainages; in other areas equivalent deposits are lumped with, and mapped as, Qae and Qam; ranges from 0 to about 10 feet (0 - 3 m) thick.*

Qap_{3-7} Pediment-mantle and terrace deposits - *Poorly to moderately sorted boulders, cobbles, sand, silt, and clay; forms a thin veneer on pediment and terrace surfaces; range from 0 to about 80 feet (0 - 24 m) thick; Qap_3 ranges from 20 to 40 feet (6 - 12 m) above Westwater Creek, the local base level; Qap_4 from 50 to 110 feet (15 - 34 m); Qap_5 from 210 to 240 feet (64 - 73 m); Qap_6 from 240 to 270 feet (73 - 82 m); and Qap_7 from 300 to 360 feet (91 - 110 m). Pediments in the northeastern area are in the Bryson Wash drainage, but labeling is continued from Westwater Creek to avoid numbering conflicts along the drainage divide.*

Qvb Lava Creek B volcanic ash - *Pale-gray to white, laminated to cross-stratified volcanic ash mixed with varying amounts of alluvial materials; is present within the highest and oldest pediment deposits (Qap_7) 5 to 10 feet (1.5 - 3 m) above the base, and is shown by a "---x---x---" line on the map; exposed along pediment base for a distance of about 1 mile (1.6 km); up to about 14 feet (4 m) thick; is 620,000 years old (Izett, 1981; Izett and Wilcox, 1982).*

Mancos Shale

Kmp Prairie Canyon Member - *Medium- to dark-gray, interlayered mudstone and siltstone, and pale- to medium-grayish-brown, fine- to very fine-grained sandstone; sandstone forms coarsening-upward sequences of several beds that are generally 1 to 5 inches (2.5 - 12.5 cm) thick; bivalves and trace fossils are locally common; has ripple laminations, sole marks, and horizontal to lenticular bedding; forms a low cuesta; thickness was 1,400 to 1,800 feet (430 - 550 m), however only about 300 feet (90 m) is preserved in the quadrangle.*

Kmbl Lower part of the Blue Gate Member - *Medium- to dark-gray, brownish-gray, or black mudstone, siltstone, and shale; weathers to pale gray; contains 0.5 to 2-inch-thick (1 - 5 cm) layers of white to light-gray bentonite and a few thin, very fine-grained sandstone beds; rare to common bivalves, ammonites, gastropods, and fish scales; trace fossils are locally common; bedding is poorly developed and is generally lenticular; unit is about 2,000 feet (600 m) thick.*

Kmf Ferron Sandstone Member - *Medium- to dark-gray, interlayered mudstone and siltstone, and pale- to medium-grayish-brown, medium- to very fine-grained sandstone; locally, base is a coarse sandstone up to 5 feet (1.5 m) thick with pebbles up to 0.5 inch (1 cm) in diameter and rare shark teeth; sandstone forms in coarsening-upward sequences that are generally 1 to 5 inches (1 - 12.5 cm) thick; bivalves, trace fossils, and calcite-cored concretions are locally abundant; has ripple laminations, sole marks, and horizontal to lenticular bedding; gradational upper contact; forms a low cuesta in the southern and eastern parts of the quadrangle; unit is about 100 feet (30 m) thick.*

Kmt Tununk Member of the Mancos Shale - *Medium- to dark-gray, brownish-gray, or black mudstone, siltstone, and shale; weathers to pale gray; contains several 0.5 to 2-inch-thick (1 - 5 cm) layers of white to light-gray bentonite and a few dense, thin, very fine-grained sandstone beds; has pods of dark-gray aragonite up to 3 inches (7.5 cm) thick; fossils and trace fossils are locally common; bivalves are locally abundant near the base of the unit; bedding is poorly developed; Coon Spring Sandstone Bed in middle; member is 150 to 200 feet (45 - 60 m) thick; lower part is 80 to 100 feet (24 - 30 m) thick; upper part is 35 to 55 feet (11 - 17 m) thick.*

Kmtc Coon Spring Sandstone Bed of Tununk Member - *Medium- to dark-brownish-gray silty shale with several yellowish-brown to pale-gray, thin, platy, sandstone beds and an interval of large, rounded sandstone concretions up to about 6 feet (2 m) in diameter; fossiliferous; sandstone is very fine grained, very thin bedded, locally hummocky, and forms beds up to about 1 foot (0.3 m) thick; gradational upper and lower contacts; mapped as a marker bed on the sandstone concretions which are commonly the only exposed part of the bed; 35 to 45 feet (11 - 14 m) thick.*

Dakota Sandstone

Kd Undivided - *Shown in cross section only.*

Kdu Upper member - *Pale-yellowish-orange to yellowish-gray, fine- to medium-grained sandstone; rarely contains quartzite cobbles up to about 4 inches (10 cm) in diameter; upper contact is a sharp, irregular surface; is medium- to thick-bedded and dominated by cross-bedding; current directions are dominantly northeast to southeast; forms a resistant bedrock cap wherever exposed; about 15 to 25 feet (4.5 - 8 m) thick in the southern part of the quadrangle; thins toward the north and pinches out near northern limit of outcrops.*

Kdm Middle member - *Medium- to dark-gray carbonaceous shale and mudstone with interlayered lenses of black coal and fine- to medium-grained, thin- to thick-bedded, cross-bedded, channel sandstone deposits; occasional plant fossils; coal forms discontinuous, boney 0.5 to 3-foot- thick (0.15 - 3 m) seams; a channel sandstone bed up to about 20 feet (6 m) thick is present in some outcrops; unit is 40 to 60 feet (12 - 18 m) thick.*

Kdl Lower member -*Pale-yellowish-orange, yellowish-gray, or gray fine- to coarse-grained, quartz sandstone and conglomeratic sandstone; medium- to thick-bedded and generally cross-bedded; conglomerate is lenticular and discontinuous; clasts in the conglomerate are generally less than 1 inch (2.5 cm) in diameter; dense ironstone concretions are abundant; about 20 feet to 50 feet (6 - 15 m) thick; basal contact is a regional unconformity.*

Kcm Cedar Mountain Formation - *Pale-greenish-gray, thin- to medium-bedded sandstone; exposed in only one small outcrop that is 18 feet (5 m) thick; total thickness is 60 to 100 feet (18 - 30 m).*

Subsurface Units

Jmb Morrison Formation-Brushy Basin Member - *Shown in cross section only; 380 to 420 feet (116 - 128 m) thick.*

Jmst Morrison Formation-Salt Wash and Tidwell Members - *Shown in cross section only; combined thickness is about 300 feet (93 m).*

Jes Entrada Sandstone and Summerville Formation - *Shown in cross section only; combined thickness is about 300 feet (93 m).*

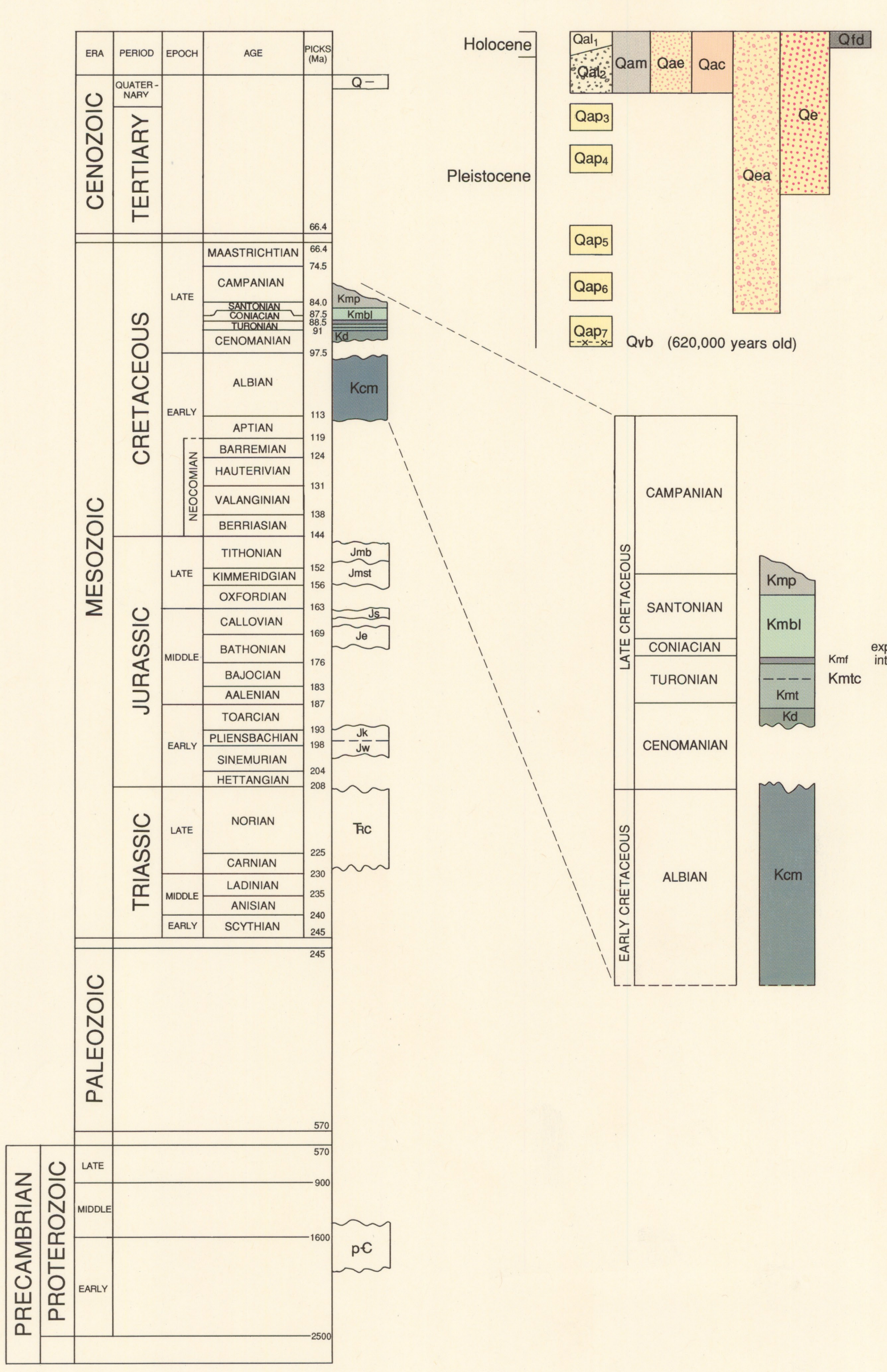
Jk Kayenta Formation - *Shown in cross section only; about 250 feet (76 m) thick.*

Jw Wingate Sandstone - *Shown in cross section only; about 300 feet (90 m) thick.*

Ꞧc Chinle Formation - *Shown in cross section only; may exceed 100 feet (30 m) thick.*

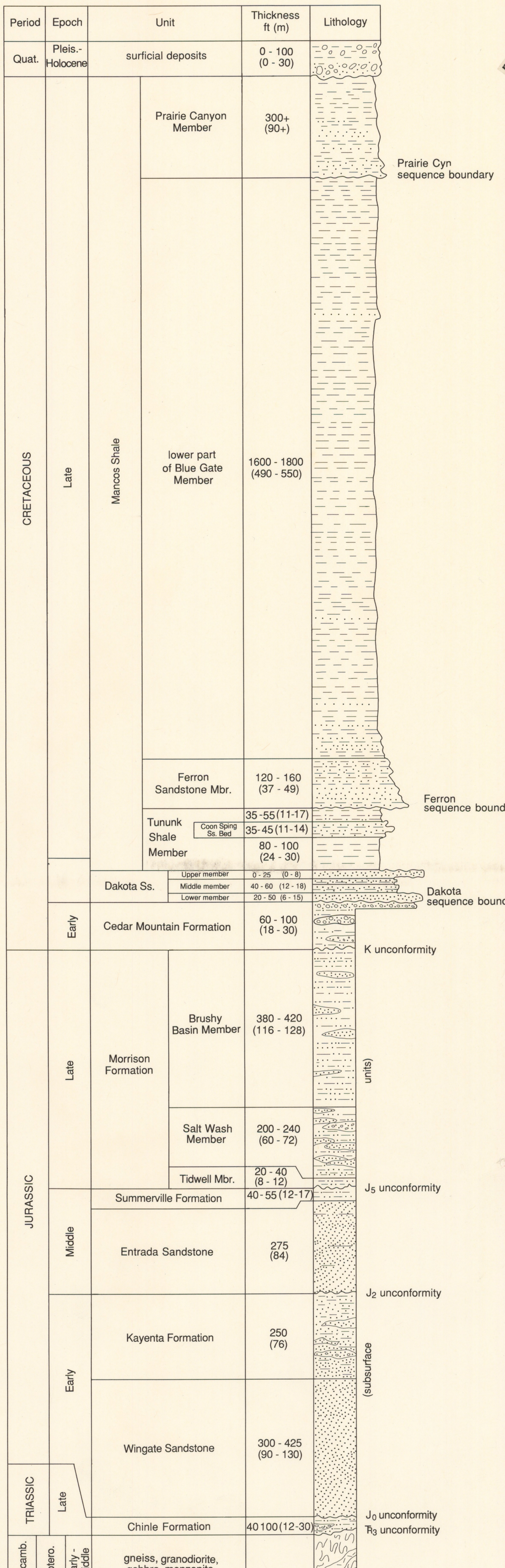
pC Undifferentiated high-grade metamorphic and intrusive igneous rock - *Shown in cross section only.*

Correlation of Map Units



MAP SYMBOLS

- Contact, dashed where approximately located
- Fault, dashed where approximately located; bar and ball on downthrown side
- Trace of axial surface of folds--arrow on axis shows direction of plunge; dotted where covered
  Anticline Syncline
- 4000 Structural contours--200 foot (60 m) contour interval, datum is top of Dakota Sandstone, long-dashed line is intermediate 100 foot (30 m) contour, short-dashed line shows where datum surface is projected above the ground surface.
- 3 Strike and dip of bedding
- Volcanic ash deposit
- Gravel or road-fill pit
- 14 Gas well; numbers refer to table 1 in text
- Well--with show of gas
- Well--dry and abandoned
- Oil or gas well--abandoned

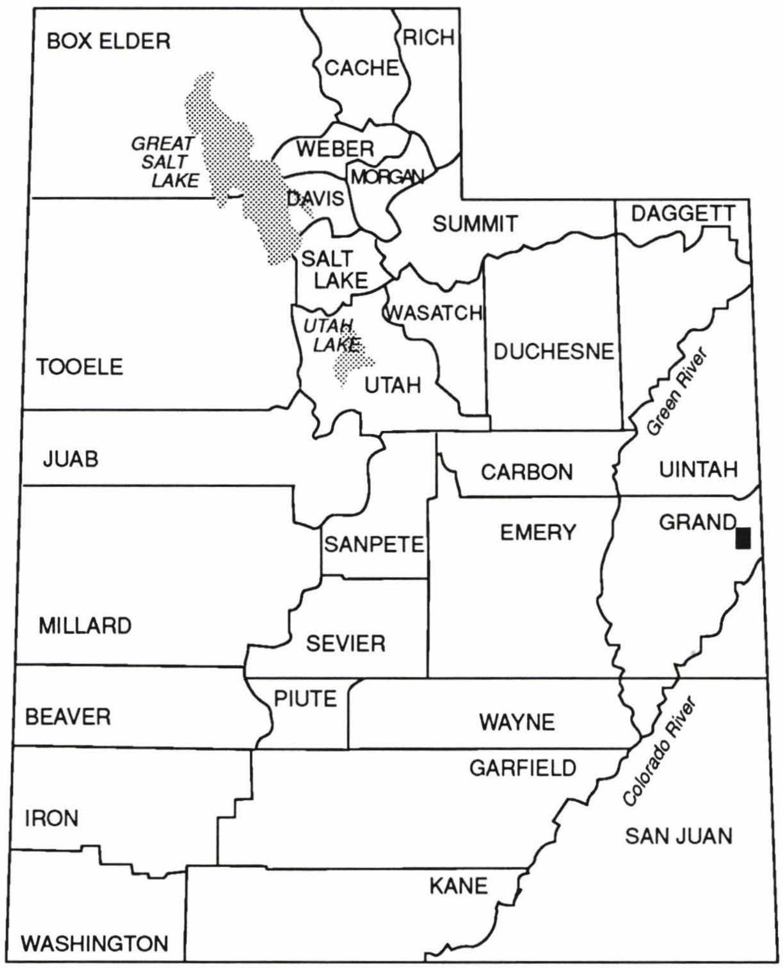


sequence boundary names from Cole and Young (1991)
unconformity names from Pipiringos and O'Sullivan 1978.

red

GEOLOGIC MAP OF THE HARLEY DOME QUADRANGLE, GRAND COUNTY, UTAH

by
Grant C. Willis
Utah Geological Survey



Map 157 **1994**
UTAH GEOLOGICAL SURVEY
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UTAH DEPARTMENT OF NATURAL RESOURCES

UTAH GEOLOGICAL SURVEY
2363 South Foothill Drive
Salt Lake City, Utah 84109-1491

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GEOLOGIC MAP OF THE HARLEY DOME QUADRANGLE, GRAND COUNTY, UTAH

by
Grant C. Willis
Utah Geological Survey

ABSTRACT

The Harley Dome quadrangle is located on the southern flank of the Uinta Basin in eastern Utah. The oldest exposed formation is the Cretaceous Aptian to Albian Cedar Mountain Formation. It is overlain by the Cenomanian Dakota Sandstone, which is mapped as three informal members. The youngest exposed formation is the Cretaceous Turonian to Campanian Mancos Shale which, in the quadrangle, consists of the Tununk Member, the Ferron Sandstone Member, the lower part of the Blue Gate Member, and the Prairie Canyon Member (new name). The Tununk Member is mapped in three parts: a lower shale, the Coon Spring Sandstone Bed, and an upper shale. The quadrangle is in a strongly erosional regime; thus, alluvial, colluvial, and eolian surficial deposits are thin and scattered. The thickest surficial deposits mantle pediments that range from 20 to 360 feet (6-110 m) above nearby drainages. The oldest pediment mantle contains the Lava Creek B volcanic ash, which was erupted 620,000 years ago.

Broad, low-amplitude, northwest-trending folds cross the quadrangle. They are probably early Tertiary Laramide structures associated with the development of the Uinta basin and the Uncompahgre uplift. The only known fault is exposed in a road cut in the southern part of the quadrangle.

Fifty petroleum exploration wells have been drilled in the quadrangle. Several wells had shows of oil, natural gas, or helium but only one has produced. Primary reservoir targets are sandy intervals in the Mancos Shale, Dakota Sandstone, Morrison Formation, and Entrada Sandstone. The Harley dome structure was set aside as a federal helium reserve in 1933, but reopened for leasing in 1964.

The quadrangle area is only intermittently inhabited, but it is an important transportation corridor. Geologic hazards of most concern are expansive, clay-bearing soil and rock, and flash floods. The expansive clays are mostly in the Mancos Shale and cause problems in highway maintenance. Rock falls are locally common in the narrow canyons in the southeastern part of the quadrangle.

INTRODUCTION

The Harley Dome quadrangle is in the eastern part of Grand County in east-central Utah (figure 1), and includes parts of the Mancos Flat and Greater Cisco oil and gas fields (figure 2). The first exploration well was drilled in 1924. The dominant structural feature within the quadrangle is the Harley dome, a northwest-trending anticline with slight closure.

The quadrangle is in the Utah portion of the Grand Valley, a broad strike valley accented with badland hills, incised arroyos,

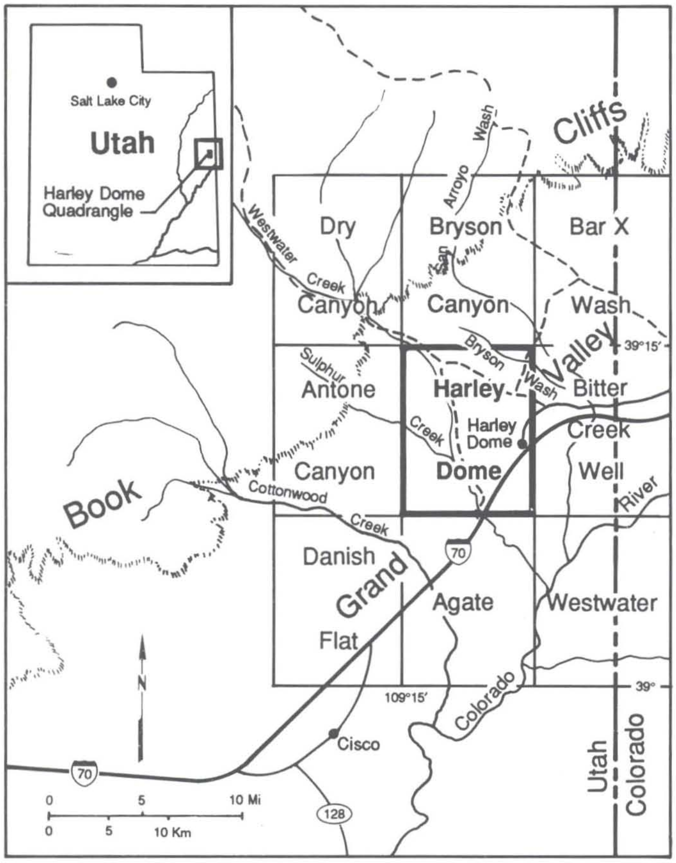

Figure 1. Index map showing the locations of the Harley Dome and surrounding quadrangles and major geographic features in the area.

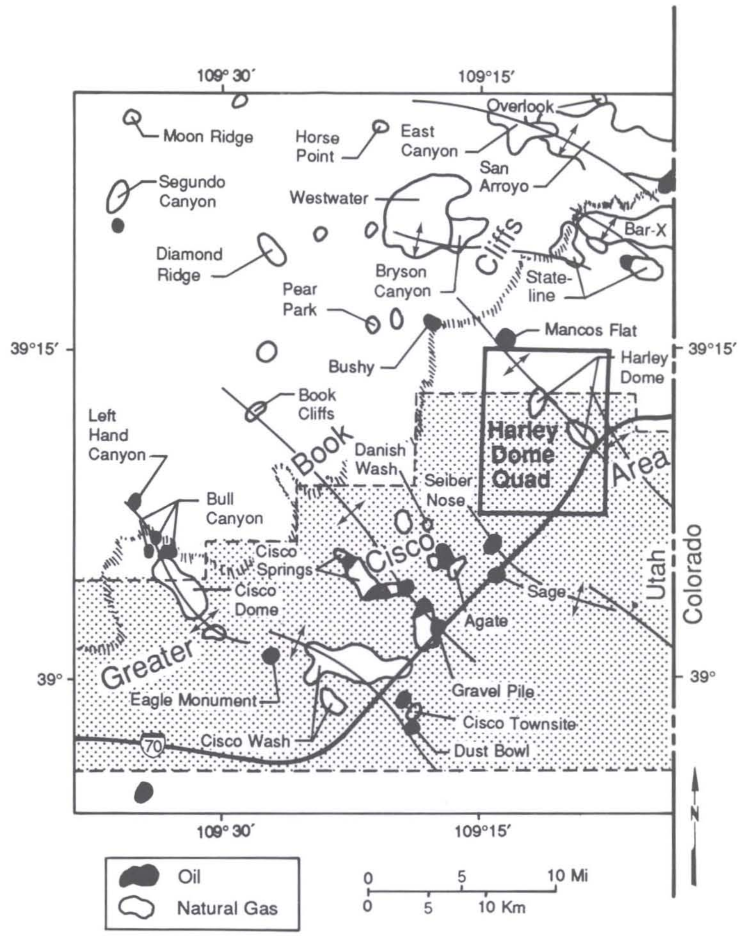

Figure 2. Map showing the location of oil and gas fields and major anticlines in the Harley Dome quadrangle area. Fields in the southern part of the area are combined to form the Greater Cisco Area field (shown as shaded area).

and erosional remnants of old pediments that slope gently southward toward the Colorado River. Grand Valley was formed by the erosional retreat of Cretaceous and Tertiary sandstone strata that overlie the thick, easily eroded Mancos Shale, and that form the Book and Roan Cliffs north of the quadrangle. Altitudes range from about 4,530 feet (1,381 m) near the southern border to about 5,100 feet (1,554 m) near the northern border. The area is dry and desolate, receiving 6 to 8 inches (15-20 cm) of precipitation a year (Waddell and others, 1981). Vegetation consists primarily of sparse grasses, rabbit brush, and saltbush, with a few stands of juniper and pinyon pine in rocky areas, and dense thickets of greasewood and tamarisk in the bottoms of washes.

The quadrangle has been crossed by important east-west transportation routes since prehistoric times, and was an important stopping point for early travelers. Westwater Creek, which crosses the quadrangle, is the major perennial stream along routes between the state of Colorado and the Green River. A major railroad crossed the quadrangle for many years until it was relocated to more stable ground south of the quadrangle. The old railroad bed can still be seen in many places. Today the quadrangle is crossed by U.S. Interstate 70, former U.S. Highway 50, several graded county roads, and by many unimproved roads and tracks.

Geology of the Book Cliffs was first documented by Peale (1878) as part of the U.S. Geological Survey-sponsored Hayden Survey. Richardson (1909) made a generalized geologic map of the Book Cliffs that included four units, the Dakota Sandstone, Mancos Shale, Mesaverde Formation, and Eocene rocks. Fisher (1936) did a more detailed study that concentrated on coal-bearing rocks. Fisher and others (1960) compiled information on the stratigraphy, paleontology, and nomenclature of the eastern Book Cliffs. The quadrangle is included in a 1 by 2 degree (1:250,000 scale) geologic map by Cashion (1973) and a 30 by 60 minute (1:100,000 scale) map by Gualtieri (1988). Willis and others (1993) mapped the Agate quadrangle to the south.

Young (1955, 1966) studied and described Cretaceous rocks in the area. Cole and Young (1991) studied the "B" member of the Mancos Shale, and Molenaar and Cobban (1991) studied the lower part of the Mancos Shale. Fouch and others (1983) summarized the chronology of Cretaceous and early Tertiary formations of eastern Utah, primarily using paleontologic data.

SUBSURFACE STRATIGRAPHY

Early to Middle Proterozoic high-grade metamorphic and intrusive igneous basement rocks, unconformably overlain by about 1,700 feet (520 m) of Triassic to Early Cretaceous strata, underlie the quadrangle (lithologic column, plate 2). Several thousand feet of intervening Proterozoic and Paleozoic rocks were eroded during the Pennsylvanian, Permian, and Triassic when the ancestral Uncompahgre highlands were uplifted and the adjacent Paradox basin was downdropped. The region-wide unconformity represents about 1.2 billion years of erosion. The Mesozoic and Proterozoic rocks are best exposed in outcrops south and southeast of the quadrangle in the Uncompahgre Plateau area, where they are dissected by canyons of the Colorado River and its tributaries.

Proterozoic

Proterozoic metamorphic and igneous rocks underlie the entire quadrangle, about 1,700 feet (520 m) below the surface near the southern boundary, and about 4,200 feet (1,280 m) below the surface near the northern border. They have been intercepted by two drill holes in the quadrangle and by several other nearby wells. Proterozoic rocks are well exposed in the Uncompahgre Plateau and Westwater Canyon areas (near the Colorado River), to the south, where Hedge and others (1968), Tweto (1987), Gualtieri (1988), Case (1991), and Willis and others (1993) mapped and described them. Case divided the Proterozoic rocks into two groups, a gneiss sequence and younger intrusive rocks, which he further subdivided into 15 map units. The gneiss sequence includes feldspathic gneiss, amphibole gneiss and amphibolite, porphyroblastic microcline gneiss, biotite-microcline gneiss, and minor quartzite, and has been dated at 1.45 to 1.7 billion years. The intrusive rocks include gneissic granodiorite, metadiorite and metagabbro, biotite granodiorite, and part of a batholith of coarse-grained, porphyritic biotite-quartz monzonite called the Vernal Mesa(?) Quartz Monzonite. These rocks have been isotopically dated at 1.45 billion years. A variety of pegmatites, aplites, lamprophyres, and metapyroxinite bodies cut the main rock units. The gneissic rocks have been metamorphosed to amphibolite facies; the intrusive rocks postdate regional metamorphism and are nonfoliated to slightly foliated.

Triassic

The Triassic in the Harley Dome area is represented only by the Late Triassic Chinle Formation. Older Triassic rocks were either never deposited or were removed by erosion that also stripped off thousands of feet of Paleozoic and Precambrian rocks (Pipiringos and O'Sullivan, 1978). The Chinle Formation is dark-reddish-brown to brown siltstone and mudstone with lenticular sandstone channel deposits and, in places, conglomerate (Willis and others, 1993). It is about 70 to 110 feet (21-33 m) thick in exposures to the south; the variation in thickness is primarily due to deposition over an irregular erosional surface. Drill-hole data indicate the Chinle may exceed 100 feet (30 m) under the Harley Dome quadrangle.

Jurassic and Lower Cretaceous

Jurassic strata include, in ascending order, the Wingate, Kayenta, Entrada, and Summerville Formations, and most of the Morrison Formation. The Wingate and Kayenta Formations have been assigned to the Triassic in many studies (for example: Cashion, 1973; Gualtieri, 1988) but others have assigned them to the Jurassic (see Hintze, 1988, p. 45 for a discussion of this problem). They are here considered Early Jurassic in age. The Entrada is Middle Jurassic and the Morrison is Late Jurassic to Early Cretaceous in age (Kowallis and Heaton, 1987).

Wingate Sandstone

The Wingate Sandstone is composed entirely of very fine- to medium-grained, quartzose, feldspathic sandstone that forms a massive vertical cliff in eastern Utah and western Colorado. It is about 300 feet (90 m) thick in exposures to the south (Willis and others, 1993) and is probably of similar thickness beneath the quadrangle.

Kayenta Formation

The Kayenta Formation is composed of ledgy-slope-forming, lenticular sandstone, siltstone, and mudstone. It commonly forms a cap and broad dip slope above the massive Wingate Sandstone. It is about 250 feet (76 m) thick based on outcrops south of the quadrangle and on drill-hole data. The Kayenta is overlain by the Navajo Sandstone in areas to the south and west; however, the Navajo thins eastward, and probably pinches out southwest of the Harley Dome quadrangle.

Entrada Sandstone

The Entrada Sandstone is composed of very fine- to coarse-grained sandstone with large-scale cross beds and lesser amounts of siltstone near the base. It is pale-gray to grayish-pink ("salmon") and forms rounded cliffs in exposures south of the quadrangle. It is about 275 feet (84 m) thick in the Harley Dome area (Willis and others, 1993).

Summerville Formation

The Wanakah Formation overlies the Entrada in southern Utah and the Summerville Formation overlies it in central Utah, but O'Sullivan (1981, 1984) and O'Sullivan and Pipiringos (1983) showed them thinning northward and eastward, pinching out south and west of the Harley Dome quadrangle. Neither formation is present in Arches National Park to the southwest (Doelling, 1985). However, during recent mapping Willis and others (1993) recognized and mapped the Summerville Formation immediately south of the Harley Dome quadrangle where it is 40 to 55 feet (12-17 m) thick. Young (written communication, 1991) stated that the Summerville is also present in western Colorado.

Morrison Formation

The Morrison Formation consists of three members, the Tidwell, the Salt Wash, and the Brushy Basin, which combined are 650 to 700 feet (198-213 m) thick (Willis and others, 1993).

The basal Tidwell Member consists of reddish-brown to gray, thin-bedded limestone, siltstone, mudstone, sandstone, and chert, and is 20 to 45 feet (6-14 m) thick. The Salt Wash consists of light-gray to light-brown, lenticular, channel sandstone beds, and red, purple, green, and gray, locally bentonitic mudstone, and is 200 to 250 feet (61-76 m) thick. The Brushy Basin, the upper member, consists mostly of red, purple, and pale-green, commonly bentonitic mudstone and siltstone with thin beds and lenses of fine- to coarse-grained sandstone. It ranges from about 380 to 420 feet (114-128 m) thick (Willis and others, 1993).

EXPOSED STRATIGRAPHY

All exposed bedrock in the Harley Dome quadrangle is Cretaceous in age, and ranges from the Cedar Mountain Formation to the Prairie Canyon Member of the Mancos Shale. Thin alluvial and eolian surficial deposits cover much of the bedrock. The alluvial sediments include deposits on pediments and terraces, and in ephemeral stream channels. Eolian deposits cover intermediate and older pediments, and some bedrock surfaces.

Cretaceous

Cedar Mountain Formation (Kcm)

Only the uppermost part of the Cedar Mountain Formation is exposed in the quadrangle. The formation is better exposed in outcrops about 0.5 miles (0.8 km) south and east of the quadrangle where it consists of light-gray to light-brown, fine- to coarse-grained sandstone and dominantly pale-green mudstone. It is locally conglomeratic and the base is generally marked by a conglomeratic bed overlying a prominent unconformity. It is separated from the overlying Dakota Sandstone by another unconformity with a hiatus of about 4 million years, and is Aptian to Albian in age (Fouch and others, 1983; Molenaar and Cobban, 1991). It was deposited in a fluvial-lacustrine environment. It is 60 to 100 feet (18-30 m) thick south of the quadrangle (Willis, and others, 1993).

The upper 18 feet (5 m) of the Cedar Mountain Formation is exposed in the bottom of a wash in the southeastern part of the quadrangle. There, it is composed of pale-pinkish-gray, yellowish-gray, or pale-greenish-gray, fine- to very fine-grained sandstone with a few limonitic concretions. The lower part is well cemented and forms resistant ledges and slopes, while the upper part is less cemented and forms slopes. Bedding is thin and planar. The upper contact is a disconformable surface, and the upper few feet of sediments may be reworked. The unconformity is marked by an irregular horizon of yellowish-brown iron oxide and, at this location, by an overlying conglomerate.

Dakota Sandstone

The Dakota Sandstone is a sequence of about 100 feet (30 m) of fluvial sandstone and littoral mudstone, carbonaceous shale, coal, and conglomerate that I divided into three informal mappable members. It is exposed in the center of the Harley dome structure and near the southeastern corner of the quadrangle (figure 3). The Dakota is Cenomanian in age (probably middle to late), and represents the last terrestrial deposition prior to transgression of the Mancos sea (Young, 1960; Fouch and others, 1983; Molenaar and Cobban, 1991).

Lower member (Kdl)

The lower member is interbedded pebble conglomerate, conglomeratic sandstone, sandstone, and mudstone. It is exposed only in a few of the deeper draws in the southeastern corner of the quadrangle where outcrops consist of pale-gray, pinkish-gray, and yellowish-gray, poorly to moderately cemented conglomerate with pebbles ranging from grit to 2 inches (5 cm) in diameter, though most are 0.25 to 0.5 inches (0.6-1.2 cm) in diameter. Most pebbles are gray, white, or black chert, dense sandstone, or quartzite and vary from clast to matrix supported. Clasts are moderately to well sorted and are subrounded to rounded. The lower member is crossbedded with sets ranging from 0.5 to 3 feet (0.15-0.9 m) thick. Current directions suggest deposition by east- to northeast-flowing fluvial systems. The lower part of the member forms resistant ledges, while the upper part is less resistant, forming slopes. I measured a thickness of 18 feet (5 m) in SE¼, section 22, T. 19 S., R. 25 E., but it is up to 50 feet (15 m) thick in the area (Willis and others, 1993).

Middle member (Kdm)

The middle member is exposed over a wider area within the quadrangle than the lower member. It is a nonresistant unit composed of interbedded carbonaceous shale, mudstone, sandstone, coal, and bentonitic clay. It is commonly covered by sandstone debris from the upper member, but where exposed it forms gray to black slopes (figure 3). It contains up to about 5 feet (1.5 m) of interbedded impure coal and bone coal, of which about one foot (0.3 m) is cleated coal. The bentonitic clay beds are pale-gray to white, altered volcanic ash (now mostly kaolin), and are 2 to 12 inches (5-30 cm) thick. Well-preserved plant fossils are common near the base of one of the clay beds. The middle member is about 60 feet (18 m) thick in SE¼, section 22, T. 19 S., R. 25 E., which is near a maximum thickness for the area. Locally, a lenticular channel sandstone cuts out most of the carbonaceous shale and coal of the middle member.

Upper member (Kdu)

The upper member is composed of resistant, thick to massive-bedded sandstone, the upper surface of which forms a long dip slope on many of the resistant ridges in the southeastern part of the quadrangle (figure 3). The sandstone varies from very fine- to medium-grained, and grains are rounded to subrounded. It is yellowish-orange, and planar to lenticular, with ripple laminations. The unit is commonly entirely sandstone, but locally, mudstone partings are present. Young (1973) considered these sandstones to be mostly tidal channel deposits. The member is 25 feet (8 m) thick in section 23, T. 19 S., R. 25 E., but thins toward the north, and is missing in section 33, T. 18 S., R. 25 E. It is overlain by the nonresistant Tununk Member of the Mancos Shale.

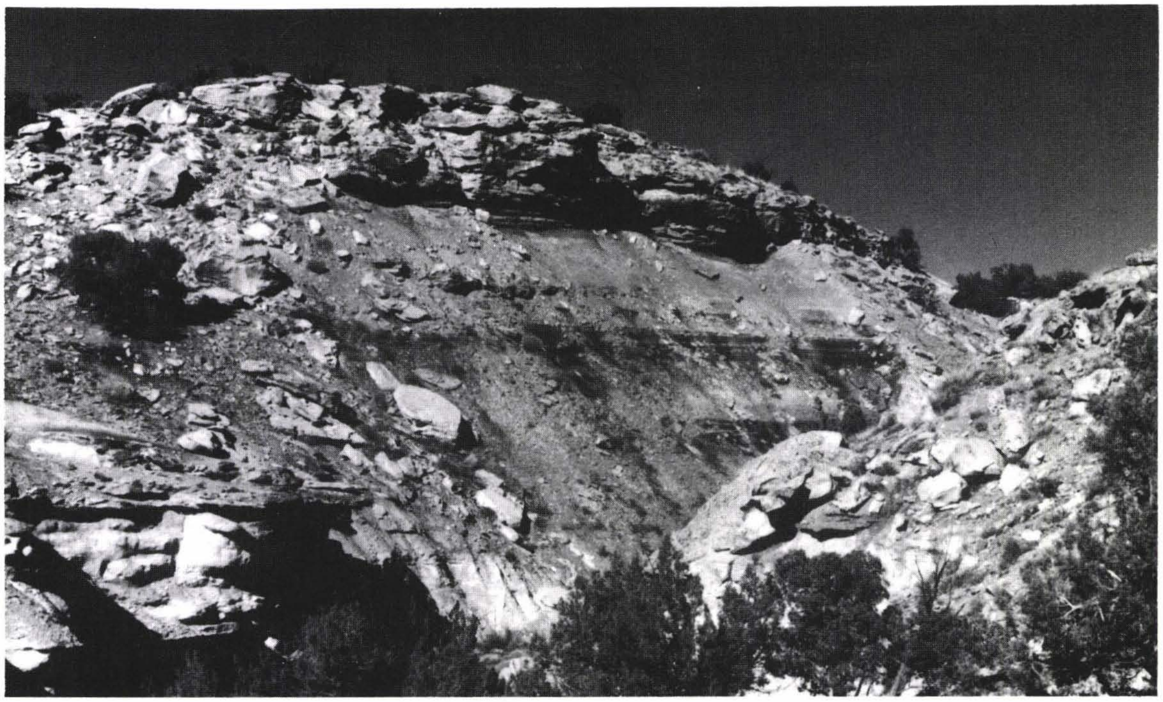

Figure 3. *Well-exposed outcrop of the Dakota Sandstone in section 22, T. 19 S., R. 25 E., in the southeastern corner of the quadrangle. The resistant ledge in the lower left is the lower member; the slope is the coal- and carbonaceous shale-bearing middle member, and the capping sandstone cliff is the upper member. At this location the middle member is thicker than is typical for the area. The middle member has been investigated for mineable deposits of coal or humates.*

Mancos Shale

The Mancos Shale is the most widespread bedrock unit exposed in the quadrangle. It is thick shale, siltstone, mudstone and sandstone that was deposited in an interior epicontinental seaway during the Late Cretaceous Cenomanian to Campanian epochs. It overlies the Dakota Sandstone and underlies the Castlegate Sandstone (the Buck Tongue of the Mancos Shale, which overlies the Castlegate Sandstone, is not preserved in the quadrangle and is not included in thickness measurements and descriptions given here). The Mancos Shale is mostly nonresistant and forms a broad strike valley with low "badland" hills and ridges held up by sandier intervals. Vegetative cover is sparse to absent due to a high alkali content; what vegetation is present is generally supported by a thin mantle of alluvial cover. The Mancos Shale is 3,400 to 3,600 feet (1,040-1,200 m) thick in drill holes north and northwest of the quadrangle, but the maximum preserved thickness in the quadrangle is only about 2,600 feet (790 m) because of erosion of the upper part.

Four members, the Tununk, the Ferron Sandstone, the Blue Gate, and the Prairie Canyon Members make up the Mancos Shale in the quadrangle. The Tununk is further subdivided into lower and upper parts separated by the Coon Spring Sandstone Bed, based on the work of Molenaar and Cobban (1991), and the Blue Gate is separated into lower and upper beds by the intertonguing Prairie Canyon Member.

Strata between the top of the Ferron and the base of the Castlegate Sandstone were informally called the main body of the Mancos Shale in this area (Hintze, 1988; Molenaar and Cobban, 1991). This interval is referred to in this report as the Blue Gate Member because it occupies a similar stratigraphic position as the Blue Gate, in the area west of the San Rafael Swell (Peterson and Ryder, 1975; Hintze, 1988). Where the Prairie Canyon Member of the Mancos Shale intertongues with the Blue Gate Member (Cole and others, in press), such as in the Harley Dome quadrangle, the Blue Gate is divided into lower and upper parts.

Subdivisions of the Mancos Shale are based on lithologic variations, primarily in the sand content of the strata. These variations reflect eustatic sea level fluctuations, which are prominent because the Mancos Shale was deposited in a shallow seaway that was sensitive to water depth and proximity to source areas (figure 4) (Molenaar and Cobban, 1991; Cole and Young, 1991).

The age of the Mancos Shale units has been defined through studies of fossils, primarily ammonoids and bivalves, combined with radiometric dating of biotite and sanidine from abundant volcanic ash and bentonitic clay (Kauffman, 1977; Fouch and others, 1983; Kauffman and others, 1987; Molenaar and Cobban, 1991; Cole and Young, 1991). The Mancos Shale is late Cenomanian to Campanian in age in this area (figure 4). The lower part of the Tununk Member is late Cenomanian to early Turonian, the Coon Spring contains early middle Turonian fauna, and the upper part of the Tununk is mostly, if not completely, late middle Turonian in age. The Ferron Sandstone Member is separated from the Tununk by a major sequence

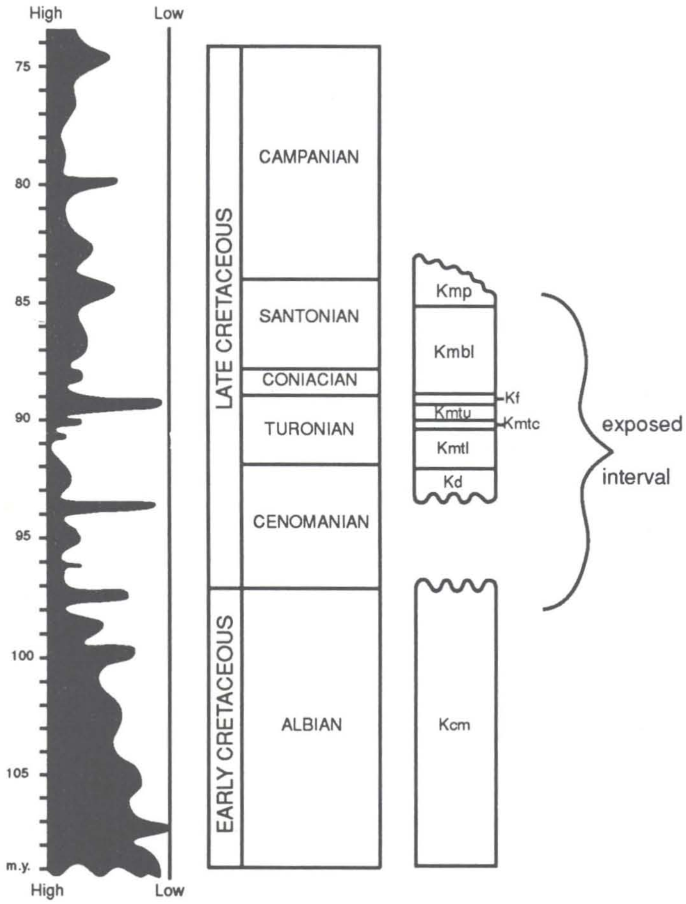

Figure 4. Ages of map units in the Harley Dome quadrangle and their relationship to the short-term world eustatic sea-level curve. Ages from Fouch and others, 1983; Hintze 1988; Molenaar and Cobban, 1991; Cole and Young, 1991; sea level curve from Haq and others, 1987; time scale from Palmer, 1983.

boundary and is late Turonian in age. (A "sequence" is "a relatively conformable, genetically related succession of strata bounded by unconformities or their correlative conformities" [Mitchum, 1977; Van Wagoner and others, 1990]). The lower part of the Blue Gate Member is Coniacian to Santonian in age. The Prairie Canyon Member, the youngest bedrock unit, is late Santonian to early Campanian in age. The base of the Prairie Canyon is another sequence boundary.

Tununk Member (Kmt): This lowest member of the Mancos Shale was divided into three parts by Molenaar and Cobban (1991). The lower and upper parts are similar in lithology and are differentiated because of the intervening Coon Spring Sandstone Bed. The Tununk is exposed in the southeastern part of the quadrangle where it forms a strike valley between the more resistant Dakota Sandstone and the Ferron Sandstone Member of the Mancos Shale. It has a total thickness of 150 to 200 feet (45-60 m) in the quadrangle.

The lower part of the Tununk Member is poorly exposed in a valley that partially circles the Harley dome. The basal contact, which is an unconformity, is sharp, marking an abrupt change from clean fluvial and tidal sandstone of the Dakota Sandstone to marine silty shale of the Tununk. A thin layer of reworked sandstone less than 3 inches (8 cm) thick at the top of the Dakota is present in some places and represents the only observable reworking by the marine transgression. The lower part of the Tununk consists primarily of medium- to dark-gray shale and silty shale that weathers to pale yellowish brown. It contains a few thin sandstone beds and grades upward to silty sandstone of the Coon Spring. The lower 20 feet (6 m) of the Tununk contains a zone of abundant oysters *(Pycnodonte newberryi)* that locally is a coquina. Bentonite beds up to a few inches thick are common in the shaley intervals. The lower part of the Tununk is 80 to 100 feet (24-30 m) thick in the quadrangle, though the gradational upper contact makes thickness measurements imprecise.

The upper part of the Tununk Member forms a generally covered slope that rises up to the base of the cuesta formed by the more resistant Ferron Sandstone Member. Where exposed it consists of shale and silty to very fine-grained sandy shale with thin bentonite and sandstone layers similar to the lower part of the Tununk. Molenaar and Cobban (1991) give it a regional thickness of 130 feet (40 m); however, within the Harley Dome quadrangle, I measured thicknesses of only 35 to 55 feet (11-17 m).

Coon Spring Sandstone Bed (Kmtc): The Coon Spring Sandstone Bed of the Tununk Member was named by Molenaar and Cobban (1991) with the type section in section 24, T. 17 S., R. 13 E., northwest of Green River, Utah. Previously, this unit was known informally as the "Dakota silt." In the Harley Dome area it is slightly to abundantly fossiliferous, and consists of silty shale with several thin, platy sandstone beds, and an interval of large, rounded sandstone concretions up to about 6 feet (2 m) in diameter. The platy sandstone is medium yellowish brown to pale gray, very fine grained, and forms beds up to about 3 inches (8 cm) thick. Fossils include bivalves *Exogyra, Pinna,* and *Inoceramus* (Kauffman, 1977; Molenaar and Cobban, 1991). Generally the unit, including the lower and upper contacts, is poorly exposed. The sandstone concretions are commonly the only exposed part of the unit; thus the unit is mapped as a marker bed (shown as a single line on plate 1) drawn on the concretionary interval. The Coon Spring Sandstone Bed is about 35 to 45 feet (11-14 m) thick, though contacts are gradational and picks are arbitrary.

Ferron Sandstone Member (Kmf): A relatively resistant sandstone interval in the lower part of the Mancos Shale forms a low but prominent cuesta throughout east-central Utah. This sandstone interval has been called the Ferron Sandstone Member on most maps and reports (Cashion, 1973; Gualtieri, 1988; Hintze, 1988 among others). Recently, Molenaar and Cobban (1991) argued that the beds exposed in eastern Utah are not part of the Ferron Sandstone Member and they proposed the term "Juana Lopez Member" be applied to this interval. "Juana Lopez" is the name used for strata in a similar position in the San Juan basin of northwestern New Mexico. They claim that the strata in question do not connect with the Ferron Sandstone around the northern end of the San Rafael Swell and are of distinctive lithology. I here retain the well-established term "Ferron Sandstone Member." The strata in question are equivalent in age to the upper part of the fluvial-deltaic Ferron

Sandstone Member at its type section and it seems most reasonable to consider them the offshore equivalent of the Ferron.

The cuesta-forming Ferron rings the Harley dome in the southeastern part of the quadrangle. It consists of fissile silty shale, sandy shale, and sandstone. The sandstone is very fine to fine grained, well sorted, and medium brown. It is thin bedded, forming beds a few inches to about a foot thick, separated by 10 to 20 feet (3-6 m) of fissile silty shale. Rounded concretions 1 to 3 feet (0.3-1 m) in diameter, commonly cored with siderite and calcite, are common in the lower part of the unit. Fossils are common, and include *Lopha lugubris* (oyster), *Inoceramus dimidius* and *I. perplexus* (bivalves), *Prionocyclus macombi*, *P. wyomingensis* and two or three species of *Scaphites* (ammonites) (Molenaar and Cobban, 1991). The base of the Ferron is a major sequence boundary (Molenaar and Cobban, 1991). It is marked by a scour surface locally overlain by lenticular lag deposits of pebbly, medium- to very coarse-grained sandstone. The lag deposits form scattered, small, ledgey outcrops a few feet thick and a few tens of feet across that are separated by a few hundred feet. Small pebbles, mostly less than 0.25 inch (0.6 cm) in diameter but up to 0.75 inch (1.8 cm), are common in the lag, and small shark teeth are sparsely scattered throughout. Though laterally discontinuous, the sandstone lag deposits are resistant and make a mappable basal contact. I measured thicknesses of the Ferron ranging from 120 to 160 feet (36-48 m) in the quadrangle. Molenaar and Cobban (1991) show thicknesses of 80 to 100 feet (24-30 m) in wells on the south side of the Uinta Basin. The variation is due to selection of different horizons for the upper contact, which is lithologically indistinct.

Lower part of the Blue Gate Member (Kmbl): The thickest and most widely distributed unit in the quadrangle is the lower part of the Blue Gate Member, which, as used here, includes the strata between the upper contact of the Ferron Sandstone Member and the base of the Prairie Canyon Member. The lower part of the Blue Gate consists primarily of medium- to dark-gray shale, silty shale, and mudstone that is variably sandy. Macrofossils are rare to absent, and bioturbation is rare to common. Weathered, the unit is pale to medium gray; fresh surfaces are dark brownish gray to brownish black. A few thin beds of very fine-grained sandstone and thin layers of altered volcanic ash are scattered through the interval. The ash beds are white to pale yellow and form prominent markers in the few areas where not covered or heavily weathered. Except for rare sandstone beds, the entire interval is nonresistant to erosion and forms a broad strike valley between the more resistant Ferron Sandstone and Prairie Canyon Members.

The lower part of the Blue Gate Member is commonly covered with a thin veneer of alluvial or eolian deposits and, even where seemingly well exposed, the surface of the unit is deeply weathered, obscuring most of the sedimentary detail. Beds that are slightly sandy take on a yellowish hue; the more sand, the yellower the color. This produces a striped appearance when viewed from a distance. In the Harley Dome area the lower part is 1,600 to 1,800 feet (490-550 m) thick, with most of the variation due to difficulties in selecting a consistent lower contact in the field and on well logs.

Prairie Canyon Member (new term) (Kmp): The uppermost preserved unit, the Prairie Canyon Member, is exposed in the western and northeastern parts of the quadrangle. There, the lower beds of the Prairie Canyon form a cuesta a few tens of feet higher than the less resistant lower part of the Blue Gate (figure 5).

The Prairie Canyon Member was previously called the Mancos "B" interval, an informal term first applied by petroleum geologists to an important gas-producing horizon in the Uinta and Piceance Creek basins (Kopper, 1962). Kopper defined the unit in a gas well located on the Douglas Creek arch about 50 miles (80 km) northeast of the quadrangle. He assigned a thickness of 385 feet (117 m) to the unit, making it a tongue within the main body of the Mancos Shale. The top of his Mancos B unit is about 575 feet (175 m) below the Castlegate Sandstone. Kellogg (1977), describing the same well, used the term "Mancos B formation". He kept the same base, and assigned 481 feet (147 m) of strata to the unit.

Cole and others (in press) renamed the Mancos "B" interval the Prairie Canyon Member. Their type locality for the Prairie Canyon Member is in and near section 7, T. 9 S., R. 103 W. in western Colorado. They recognized the same lower Prairie Canyon contact as the earlier workers, but described the upper contact as variable. In this area, the upper contact is picked at the top of a thick, resistant, orangish-gray calcareous sandstone exposed north of the quadrangle. Although not exposed in the Harley Dome quadrangle, overlying beds are called the upper part of the Blue Gate Member.

The base of the unit is a sequence boundary, probably second order, and is a sharp, well-defined contact on well logs and in many outcrops (Cole and Young, 1991). The sharp contact is due to sand-rich strata directly overlying uniform shale and mudstone. In many locations in the area, the contact is a scour surface with channels a few feet deep cut into the underlying shale. This sharp, scoured surface is not well exposed anywhere in the quadrangle, but its position is near the base of the cuesta held up by the more resistant sandstone and mudstone of the Prairie Canyon Member (figure 5).

The Prairie Canyon Member consists of interbedded, thin-bedded, very fine- to fine-grained sandstone, mudstone, siltstone, and shale. It is slightly to moderately fossiliferous with inoceramids (bivalves), *Scaphites* and *Baculites* (ammonites), among others (Cole and Young, 1991). Cole and Young described five lithofacies in the unit, including silty claystone, sandstone-claystone, sandy siltstone, bioturbated muddy sandstone, and sandy dolomite, that form coarsening-upward parasequences. Bioturbation varies from rare to common. They also described the Prairie Canyon Member as a prodelta-plume deposit, related to wave-dominated deltas to the north and west, that accumulated during repeated episodes of scouring, winnowing, and redeposition on a shallow continental shelf. Prior to Cenozoic erosion, the Prairie Canyon was 1,400 to 1,800 feet (430-550 m) thick in the area. However, in the quadrangle the upper part has been removed by erosion leaving only about 300 feet (90 m) of the unit.

Quaternary

The quadrangle is on the Colorado Plateau, an area that is undergoing relatively rapid downcutting and erosion. Thus, surficial deposits are mostly young, thin, and scattered. Older

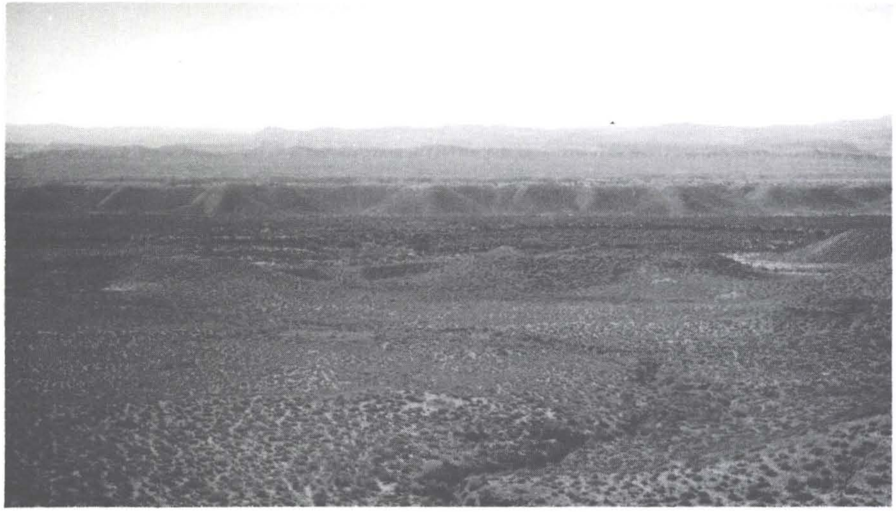

Figure 5. Looking west across Westwater Creek, which flows left through the low area in the middle of the photograph. Pediment-mantle deposits Qap4 cover the cut surface just beyond the creek. The creek bedforms level 1 and the bushes are growing on level 2. A cuesta held up by resistant sandstone beds in the lower part of the Prairie Canyon Member is visible in the middle distance. The Book Cliffs are visible in the background. Photograph taken from section 1, T. 19 S., R. 24 E.

surficial deposits are limited to remnants on pediments and terraces (figure 6). Thin layers of eolian sand and silt blanket areas subject to less erosion. Mappable mass-movement deposits are absent due to low topographic relief.

Quadrangle topography is dominated by pediments and terraces up to 360 feet (110 m) above adjacent drainages that are blanketed by alluvial deposits less than 100 feet (30 m) thick (figure 6). Each of these surfaces is beveled across bedrock and represents a period of temporary stabilization. Numerous pediment and terrace levels exist in the quadrangle; as many as 17 slightly different levels can be counted between Westwater Creek, the major base level control in the quadrangle, and the highest pediment surface. However, many are of limited areal extent or they merge laterally with slightly higher or lower levels. Thus, for mapping, active deposits and deposits mantling pediments and terraces have been combined into seven units. Deposits on active alluvial surfaces and on the lowest levels are mapped as younger alluvial deposits (Qal_1). Deposits on the six older levels are called older alluvial deposits (Qal_2), and pediment- and terrace-mantle deposits (Qap_3 to Qap_7). Numbers designate relative age; Qal_1 are young, presently accumulating deposits, and Qap_7 are the oldest. Map units without numbers generally have a broader range in age. In addition, deposits on individual surfaces within one map unit may vary in age. For example, because of active downcutting and immature drainage development, a surface at the bottom of an active wash at one location is dissected and 10 to 30 feet (3-9 m) above the wash a short distance downstream.

Alluvial pediment- and terrace-mantle deposits (Qap_3-Qap_7)

Alluvial pediment- and terrace-mantle deposits consist of a thin veneer of poorly to moderately sorted sand, gravel, and boulders with minor silt and clay covering planar erosional surfaces developed on the Mancos Shale. Some of these surfaces are terraces of Westwater Creek, but in many locations it is impractical to distinguish terraces from pediments, thus all are lumped into one category. Deposits on the youngest of these beveled surfaces are mapped as Qap_3. Qap_3 ranges from 20 to 40 feet (6-12 m) above Westwater Creek, Qap_4 includes several surfaces of slightly different elevations between 50 and 110 feet (15-34 m) above the creek, Qap_5 ranges from 210 to 240 feet (64-73 m), Qap_6 ranges from 240 to 270 (73-82 m), and Qap_7 ranges from 300 to 360 feet (91-110 m).

The age of the surfaces and deposits can be estimated using the Lava Creek B volcanic ash (Qvb) near the base of the oldest pediment mantle as a control point (Willis, 1992); by comparing the shape, height, and location of the pediments; and by comparing the amount of pedogenic calcium carbonate buildup in the soil profile (Machette, 1985) (see Correlation of Pediment- and terrace-mantle deposits diagram on plate 2). Qap_7 has a stage IV+ to stage V carbonate buildup; Qap_5 and Qap_6 have a stage IV to V; Qap_3 and Qap_4 have a stage II to II+ buildup; and in Qal_1 and Qal_2 the calcium carbonate buildup is minimal to absent.

There is a gap of more than 100 feet (30 m) in elevation between Qap_4 and Qap_5, suggesting a large time difference between the oldest three and youngest four surfaces. In addition, Qap_5 and older surfaces trend southeastward as opposed to the younger surfaces which show southward-directed drainage. The older surfaces are obviously related to an earlier Westwater Creek that flowed east of the Harley dome. At some time between Qap_5 and Qap_4 the drainage was captured and diverted west of the anticline.

Lava Creek B volcanic ash deposits (Qvb)

A layer of Lava Creek B volcanic ash (indicated by an alternating "dash-x-dash" line on the map) is present near the base of the highest, oldest, and thickest pediment-mantle deposits (Qap_7) in sections 19 and 20, T. 18 S., R. 25 E., in the northern part of the quadrangle. The ash deposit consists mostly of volcanic glass shards mixed with varying amounts of very fine-grained quartz sand. It overlies a thin gravel layer, never sitting directly on the cut bedrock surface. The deposit is up to about 14 feet (4 m) thick near the middle of the outcrop, and thins toward the northwest and southeast. The unusual thickness is due to ponding by alluvial and eolian processes, possibly in a protected hollow near or on the then-active alluvial surface. It is impossible to determine the thickness of the ash at the time it was deposited across the area.

The ash is tentatively identified as the Lava Creek B, a member of the Pearlette family of ashes dispersed from a volcanic eruption in the Island Park/Yellowstone area of eastern Idaho and

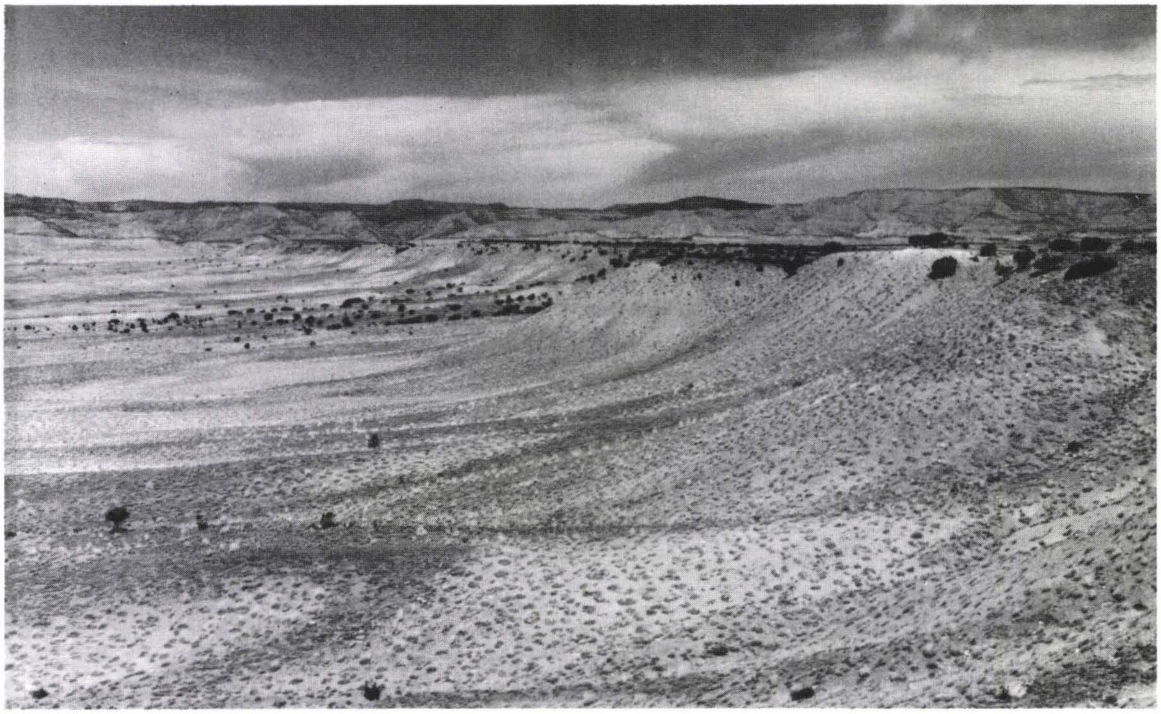

Figure 6. *Looking northwest along the erosional escarpment of the oldest pediment level in the quadrangle, Qap_7. White patch near the right edge is pedogenic calcium carbonate. The Book Cliffs are visible in the background. Photograph taken from section 28, T. 18 S., R. 25 E.*

western Wyoming about 620,000 years ago (Izett, 1981; Izett and Wilcox, 1982). This identification is important in interpreting the Quaternary history of this part of the Colorado Plateau. It documents about 360 feet (110 m) of downcutting by the Colorado River in less than 620,000 years, an average rate of about 0.6 feet (0.18 m) per thousand years (Willis, 1992). The same ash is also found in pediments of about the same height in western Colorado (Robert Young, personal communication, 1990), indicating that a widespread, stable, depositional surface (or surfaces) existed at that time.

Alluvial stream and slope-wash deposits (Qal_1-Qal_2)

Thin deposits of moderately to poorly sorted, clay- to boulder-size alluvial material are present along most streams and washes. This material has been divided into younger and older deposits near well-established streams (Westwater and Sulphur Creeks) where it forms larger, more distinctive deposits. The younger deposits (Qal_1) are in or near the bottoms of active channels and the older deposits (Qal_2) are dissected and are 10 to 30 feet (3-9 m) above active channels. Along smaller washes, and in smaller deposits where the differences are less distinctive or are too small to map, deposits at levels of Qal_1 and Qal_2 are lumped together, and are included in map units Qae and Qam. Qal_1 and Qal_2 deposits are generally better sorted and contain more material derived from formations outside the quadrangle whereas units Qae and Qam are mostly locally derived. Qal_2 deposits are probably late Pleistocene and Qal_1 are mostly Holocene.

Alluvial mud and sheet-wash deposits (Qam)

Many broad, generally flat or gently sloping areas are covered with silt, clay, and some sand weathered from nearby outcrops of Mancos Shale or from the middle member of the Dakota Sandstone. Locally, the deposits are mixed with sand or minor gravel- to boulder-sized material eroded from nearby pediments or outcrops and with eolian silt and sand. They generally have had limited alluvial transport and locally may be from in-situ weathering of muddy outcrops. They form a thin cover over the bedrock. They are generally equivalent in age, and grade laterally into deposits Qal_1, Qal_2, Qae, and Qea.

Mixed alluvial and eolian deposits (Qae)

Mixed alluvial and eolian deposits consist of moderately sorted alluvial clay- to boulder-sized material but are generally dominated by finer-grained materials. The eolian component varies from low to moderate. Locally, they contain some colluvial materials. They are present on broad slopes and in low areas with minor drainages and limited runoff that are dominated by slope-wash and in small ephemeral washes. Qae deposits are gradational with, and locally similar to, Qea, Qam, Qal_1, and Qal_2 deposits. They are up to 20 feet (6 m) thick.

Mixed alluvial and colluvial deposits (Qac)

Along the erosional escarpments of many of the dissected pediments, the coarse-grained pediment veneer is being undercut and spilling down the slopes below. This colluvium is commonly mixed with alluvial materials, forming mixed alluvial and colluvial deposits. The deposits are generally poorly sorted and are localized. They commonly obscure the contact between the bedrock and the pediment veneer. Such materials are common on slopes throughout the quadrangle, however, only the larger and more continuous deposits are mapped separately. Smaller deposits are included within other alluvial or bedrock units. These deposits are generally equivalent in age to Qa_1 and Qa_2.

Mixed eolian and alluvial deposits (Qea)

Many of the broad pediment surfaces in the quadrangle are blanketed by mixed eolian and alluvial deposits (Qea). Normally, there is little erosion on these surfaces because downcutting has entrenched washes that crosscut and border the surfaces. Most precipitation sinks into the porous cover. Therefore, the surfaces gradually collect eolian dust and sand. Some alluvial reworking occurs during heavy storms. The eolian material is a distinctive pinkish- to orangish-gray color because its source includes Mesozoic rocks that make up the "redrocks" country to the southwest, the prevailing up-wind direction. In contrast, alluvial material in the quadrangle is derived locally from Cretaceous and Tertiary rocks to the north that have a predominantly yellowish-brown to gray color. The eolian deposits represent a systematic buildup over a long period of time and range in age from 600,000 years to the present. However, they have limited use as an age indicator because erosion has removed much of the buildup on the oldest pediments. They range up to about 10 feet (3 m) thick.

Eolian deposits (Qe)

Elevated, flat to slightly dipping benches on the resistant Dakota Sandstone, in the southeastern part of the quadrangle, act as collecting areas for eolian sand and silt. These deposits are better sorted than the mixed eolian and alluvial deposits (Qea) and generally do not contain alluvial materials. In some locations they are beginning to form dune-like mounds, though true dunes have not yet formed. Their age is poorly known, but they are significantly younger than the oldest Qea deposits.

Fill deposits and disturbed areas (Qfd)

Fill and disturbed areas are scattered throughout the quadrangle. During construction of Interstate 70 a large gravel pit was opened in section 20, T. 19 S., R. 25 E., in the south-central part of the quadrangle. Within this pit are several large piles of waste material from screening and washing operations. This pit and waste pile area is shown as a map unit. Smaller gravel pits are labeled on the map. Other small, unmapped fill includes base material for I-70, U.S. 50, and an old railroad grade, and several small dams constructed across ephemeral washes to catch rain and snow runoff for stock and wildlife watering.

STRUCTURE

Regional Setting

The quadrangle is about 20 miles (32 km) east of the buried ancestral Uncompahgre fault, a northwest-trending, down-to-the-southwest, reverse fault with about 20,000 feet (6,000 m) of vertical displacement and more than 30,000 feet (9,000 m) of horizontal offset (Frahme and Vaughn, 1983) (figure 7). The Uncompahgre fault was active primarily from late Paleozoic to about Middle Triassic time. During that time the Paradox basin, a deep basin southwest of the fault, filled with up to 20,000 feet (6,000 m) of clastics, carbonates, and evaporites. At the same time, about 2,000 feet (600 m) of Paleozoic sedimentary rocks and a large, but unknown, thickness of Precambrian metamorphic, igneous, and sedimentary rocks were eroded from the upthrown block east of the fault. By Late Triassic time the fault was inactive and topography had been subdued enough to allow the Chinle Formation to be deposited across the region. The upthrown block continued to exert some influence on deposition throughout the Mesozoic, causing noticeable thinning and pinchouts in several formations that extend onto the block (Heyman and others, 1986).

The Laramide orogeny began to fold strata in the area during the Late Cretaceous, probably Campanian time (Johnson and Finn, 1986; Lawton, 1986). However, large structures in the region such as the Uinta and Piceance Creek basins, Douglas Creek arch, and Uncompahgre uplift formed primarily during the Paleocene and Eocene (Gries, 1983; Johnson, 1985, 1989; Johnson and Finn, 1986). Detailed studies have not been done on many of the small secondary structures such as the Harley dome, however, they are assumed to have formed contemporaneously with the larger structures. Since no sediments younger than Campanian age are preserved near the Harley dome, there is no direct way of determining its age of development.

Local Structure

The Harley Dome quadrangle lies on the southeastern flank of the Uinta basin near the Douglas Creek arch, a northward-trending anticline that separates the Uinta and Piceance Creek basins. Overall, strata dip northwest, toward the Uinta basin axis, generally at less than 5 degrees. However, broad, gentle, mostly northwest-trending, second-order folds with wave lengths of a few miles, cross the area. One such fold, Harley dome, covers much of the quadrangle (figure 8). It has minor closure of about 100 feet (30 m), and is asymmetric, with dips on the eastern flank ranging up to about 20 degrees and to about 8 degrees on the west flank (plate 1).

Limited exposures suggest the presence of small subsidiary folds with northeast-trending axes on the northeastern flank of the anticline. The subsidiary folds are in an area of small isolated outcrops of Dakota Sandstone in which the strike varies from N. 80° W. to N. 5° E. and dips vary from 8° to 45° E. to NE. Overall, as shown by structural contours on plate 1, strike in the area is northwest and dips are less than 20 degrees. These subsidiary folds may be related to slumping, to the asymmetric nature of Harley dome, or to interaction of Harley dome and Bitter Creek anticline which merge, forming a "Y," a short distance to the southeast (plate 1). Alternatively, the variation in bedding orientation may be a depositional feature rather than structural folds. The Dakota Sandstone has an irregular, hummocky upper surface where better exposed to the south.

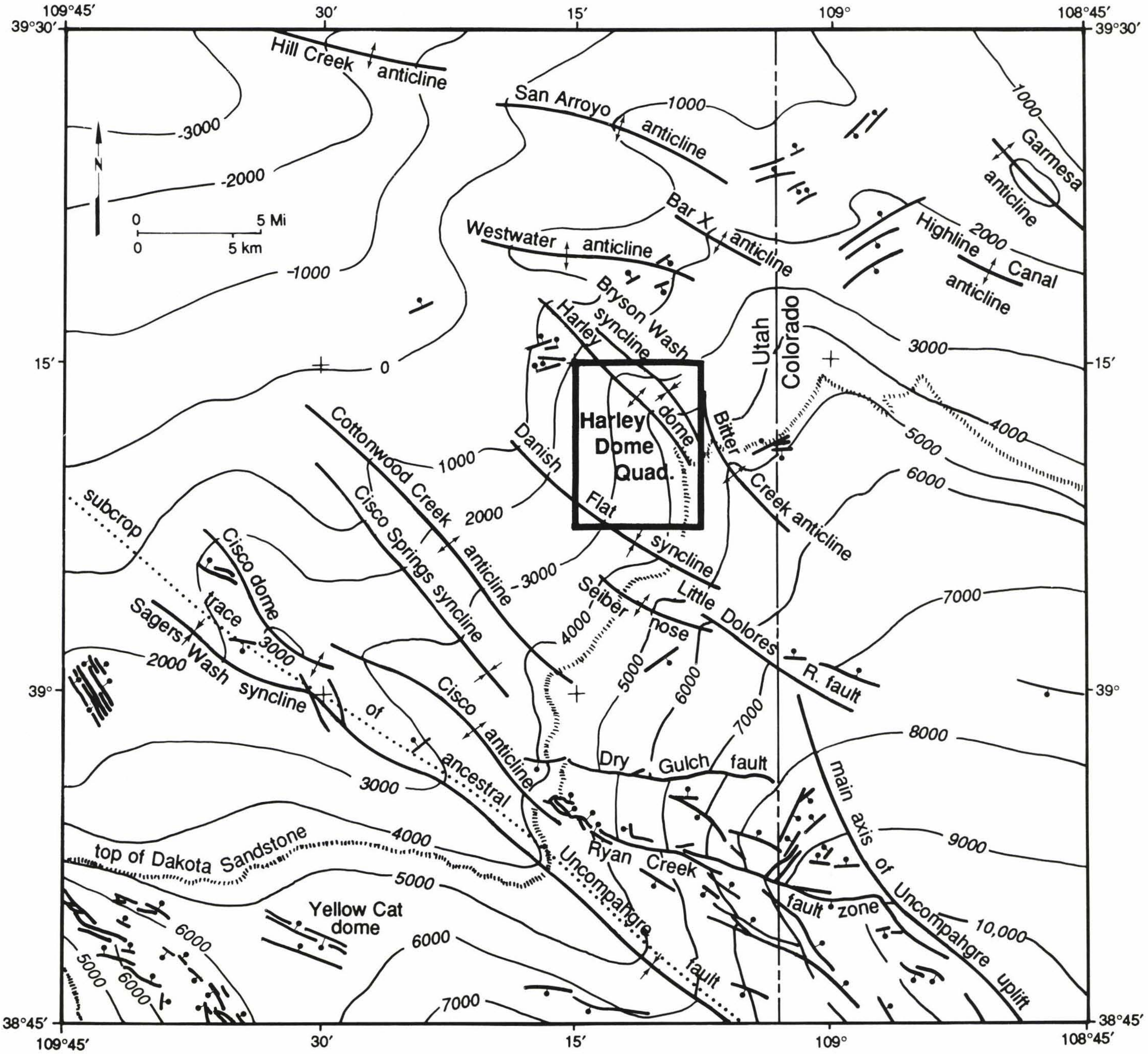

Figure 7. Simplified structural contour map showing the regional setting of the Harley Dome quadrangle. One-thousand-foot (300 m) contours are shown on the top of the Dakota Sandstone, the outcrop of which is indicated by the hachured line (modified from Williams, 1964 and Cashion, 1973).

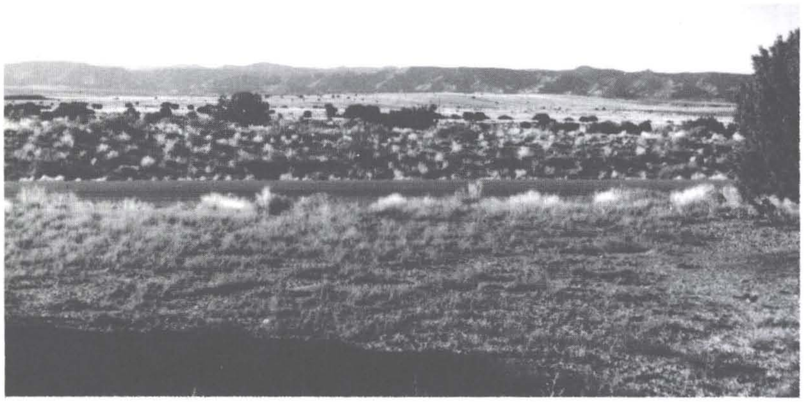

Figure 8. Looking northwest across the crest of Harley dome. The dome is defined by the gently sloping, light-colored surface which is the resistant, capping bed of the Dakota Sandstone. The much less-resistant Tununk Member has eroded back, forming a depression around the dome. Photograph taken from section 10, T. 19 S., R. 25 E.

Harley dome is flanked by Danish Flat syncline, which crosses the southwestern corner of the quadrangle, and by Bryson Wash syncline to the northeast (figure 7). Bitter Creek anticline extends into the northeastern part of the quadrangle. All of these structures are subtle, deflecting bed orientations only a few degrees.

The only known fault is a small reverse fault with 10 to 15 feet (3-4.5 m) of offset exposed in a road cut along U.S. Interstate 70. It cannot be traced beyond the road cut. Young (1983, plate 1) showed a northwest-trending, down-to-the-northeast fault crossing the northeastern part of the quadrangle close to the axis of the Bryson Wash syncline. Gualtieri (1988) does not show a fault in the same location, instead showing a steeper and larger fold limb on the east flank of the Harley dome. This area is covered by surficial deposits for most of its length. However, even where the Mancos Shale is exposed, weathering and the lack of good marker beds preclude field recognition of the fault. I follow Gualtieri's (1988) interpretation and show a fold rather than a fault on the map (plate 1). The main reason is that neither the Dakota Sandstone, on trend with the fault to the southeast, nor the Castlegate Sandstone, on trend to the northwest, are offset where the fault is projected to cross them. However, there is room for a fault between the outcrops, which are about 12 miles (19 km) apart.

ECONOMIC GEOLOGY

Oil and Natural Gas

The southern part of the Harley Dome quadrangle is within the Greater Cisco Area oil and gas field, a cluster of several small fields in eastern Grand County, and the northern part contains part of the small Mancos Flat field (figure 2). The first well in the quadrangle, drilled in 1924, was reported as dry and was abandoned (table 1) (Stowe, 1972). Exploration has been sporadic, with pulses of activity in the mid 1950s, late 1960s, late 1970s, and early 1980s, with a few wells drilled in intervening periods. The most recent well was drilled in 1986. Production was hindered by the presence of carbon dioxide, nitrogen, and helium (R.G. Young, written communication, 1991).

The Harley dome was set aside as a U.S. Government helium reserve in 1933. That status was revoked in 1964 after further evaluation of the field (Federal Register, August 8, 1964, p. 11,455). The Greater Cisco Area field is primarily a gas field, though oil has also been produced. Production is from sandy zones in the Mancos Shale, and sandstones in the Dakota Sandstone, Morrison Formation, and Entrada Sandstone. Young (1983) stated that the gas was probably derived primarily from carbonaceous material in the Mancos, Cedar Mountain, Dakota, and Morrison Formations. He also suggested that the oil may have migrated eastward and up section from Pennsylvanian strata in the deep and prolific Paradox basin about 20 miles (32 km) to the southwest.

Coal and Humates

The Dakota Sandstone contains carbonaceous shale and coal with some mudstone and thin-bedded sandstone that has been investigated both for coal and for humates (figure 3). The coal is thin, lenticular and is generally impure. Jackson (1983) reported from 3,000 to 9,000 BTU per pound (340-1,020 kg-calories per kg), making the coal a subbituminous C or lower rank (table 2). Ellis and Hopeck (1985) reported no seams greater than 30 inches (75 cm) thick in the area. I found no seams greater than 24 inches (60 cm), and most are less than 12 inches (30 cm) thick. The primary economic advantage is that the coal is close to, or at, the surface in the southeastern part of the quadrangle where overburden is 100 feet (30 m) or less over most of at least 5 square miles (13 km^2). Dakota Sandstone coal beds in the quadrangle have never been defined as part of a coal field. The closest coal field focused on seams in the Dakota Sandstone is the La Sal field in southeastern Grand and northeastern San Juan Counties (Doelling and Graham, 1972, p. 274). They reported analyses of six coal samples from that area that ranged from 9,300 to 14,750 BTU per pound (1,064-1,688 kg-calories per kg). That coal is low in moisture and high in fixed carbon, both desirable qualities, but it is also relatively high in ash and sulfur.

Though the coal in the Dakota Sandstone shows limited potential as a combustible resource, the carbonaceous interval has generated considerable interest as a source of humates (Jackson, 1983). Humates are used in agriculture as a soil conditioner and are leached to produce liquids for use in health foods. Though value per ton is low compared to coal, humates can be economical when large volumes with limited overburden are easily accessible. The mineable zone is 20 to 40 feet (6-12 m) thick and is continuous throughout the southeastern part of the quadrangle and in adjacent quadrangles, except where incised by paleochannels and by modern canyons.

Table 1.

Oil and gas wells of the Harley Dome quadrangle. Tops of the Dakota and Entrada Sandstone determined from well logs where available, others are from driller reports (d symbol) and are unverified. The reported log pick for the top of the Dakota is a marker bed 20 to 30 feet (6-9 m) above the contact in the lowermost part of the Tununk Member. This marker is used because it gives a consistently strong kick on gamma ray and resistivity logs, while the upper part of the Dakota varies lithologically and the top varies on well logs. Abbreviations: BBLO - barrels of oil, MCFG - thousands of cubic feet of gas, BBLW - barrels of water. Status codes: oil - completed oil well; gas - completed gas well (production figures show that several completed gas wells have never been put into production); S.I. - shut-in; D&A - dry and abandoned; G - gas show; A - abandoned producer showing year abandoned. Crawford (1963) stated that "initial production of natural gas was 3,050,000 cubic feet per day" in Ute Royalty Corporation Government No. 1 (Map No. 26) well. The well was abandoned without being put on line.

Map No.	Location (¼ sec.-sec.-T.-R.)	Operator and Well Name	Completion Date	Total Depth (feet)	Formation at Total Depth	Top of Dakota Ss, Entrada Ss (above sea level)	Producing Formations	Cumulative Production (BBLO, MCFG, BBLW)	Status
1	SESWSW 11-18S-24E	William Bush Capansky 11-4	06/08/83	1580	Mancos	-- --	Mancos	976 0 0	Oil A-1987
2	SWNESW 13-18S-24E	Willard Pease Oil Federal 13-2	01/10/80	2724	Entrada	3426d 2678d	--	--	D&A
3	NWNWNW 14-18S-24E	William Bush Bush 14-2	03/28/86	1700	Mancos	-- --	--	--	D&A
4	NWSENW 24-18S-24E	Willard Pease Oil Federal 24-3	01/27/83	2103	Morrison	3529 --	--	--	D&A
5	NENWNE 25-18S-24E	Great Western Drilling Federal 2	05/25/55	2213	Entrada	3531d 2773d	--	--	D&A
6	CSESE 27-18S-24E	Bookcliff Petroleum West Bitter Crk 27-44	09/19/82	1830	Entrada	? ?	--	--	D&A
7	CWSWSW 15-18S-25E	Ambra Oil & Gas Harley Dome 15-1	12/12/83	2280	Morrison	3118 --	--	--	D&A
8	CNSENE 15-18S-25E	B. Long & B. Howell B. Long Federal 1	11/08/64	1890	Morrison	3280 --	--	--	D&A
9	SWNENW 17-18S-25E	Carter Oil Ruby Basher 1	08/21/55	2800	Morrison	2531d --	--	--	D&A
10	CNESE 17-18S-25E	Ambra Oil & Gas Harley Dome 17-1	12/18/83	2500	Morrison	2839 --	--	--	D&A
11	CSESW 19-18S-25E	Ambra Oil & Gas Harley Dome 19-1	07/25/83	1668	Morrison	3977 --	--	--	D&A
12	NWNWSW 19-18S-25E	Belco Petroleum Harley-Govt 2	03/30/60	1980	Entrada	3838 3005	--	--	D&A
13	SESWNW 20-18S-25E	Carter Oil Harley Basher 1	07/28/55	2300	Entrada	? 2842d	--	--	D&A-G
14	SWSWNW 20-18S-25E	Thunderbird Oil Larson-Federal 20-1A	08/30/73	2000	Entrada	3960 3070	--	--	D&A
15	CSWSE 21-18S-25E	Ambra Oil & Gas Harley Dome 21-2	12/27/83	1600	Morrison	3884 --	--	--	D&A
16	CESWSW 21-18S-25E	Ambra Oil & Gas Harley Dome 21-1	08/15/83	1640	Morrison	4044 --	Dakota	0 0 0	Gas S.I.
17	CWSWSE 27-18S-25E	Bookcliff Petroleum West Bitter Creek 27-33	10/25/82	1830	Entrada	4482d 3630d	--	--	D&A-G
18	NWNESW 27-18S-25E	Lansdale A Govt 8	08/10/69	1540	Entrada	4288d 3388d	Morrison	0 0 0	Gas S.I.
19	CNWSE 27-18S-25E	Texota Oil Govt 1-E	05/07/56	1540	Entrada	4383 3489	--	--	D&A
20	SWSESE 27-18S-25E	Lansdale A Govt 18	01/00/69	1155	Entrada	4556d 3734d	Morrison	0 0 0	Gas A-1984
21	NWNWSW 29-18S-25E	Texota Oil Federal 1	12/10/55	1534	Summerville	4284 --	--	--	D&A-G
22	SWNESW 29-18S-25E	Lansdale A Lansdale-Govt 3	07/14/67	1392	Entrada	? ?	--	--	D&A
23	SWSWNE 30-18S-25E	Belco Petroleum Harley-Govt 1	03/21/60	1233	Morrison	4078 ?	Morrison	0 0 0	Gas S.I.
24	SWSWSE 30-18S-25E	Lansdale A Federal 11	11/29/78	1534	Summerville	3995d --	Dakota	0 0 0	Gas A-1979

Table 1 (continued)

Map No.	Location (¼ sec.-sec.-T.-R.)	Operator and Well Name	Completion Date	Total Depth (feet)	Formation at Total Depth	Top of Dakota Ss, Entrada Ss (above sea level)	Producing Formations	Cumulative Production (BBLO, MCFG, BBLW)	Status
25	NWNWNE 31-18S-25E	Lansdale A Lansdale-Govt 12-X	07/14/77	1494	Morrison	4014 --	--	--	D&A
26	NWNWNE 31-18S-25E	Ute Royalty Corp. Govt 1	09/12/55	1122	Morrison	4014 --	Morrison	0 0 0	Gas A-1955
27	SWSWNE 32-18S-25E	Broadhead Walter Lansdale-State 32-1	07/10/80	805	Morrison	4469 --	--	--	D&A
28	NENESW 33-18S-25E	Lansdale A Govt 2	06/20/69	1100	Entrada	4818d 3981d	--	--	D&A
29	SENWNW 33-18S-25E	Wilson & Tilton Larson-Phillips Fed	05/23/55	1197	Entrada	4616d 3796d	--	--	D&A
30	SESWSE 33-18S-25E	Lansdale A Lansdale-Govt 1	12/18/67	944	Entrada	surf. 4055	Morrison	0 0 0	D&A
31	SESWNW 33-18S-25E	Lansdale A Lansdale-Govt 6	03/29/68	1200	Entrada	4729d 3929d	--	--	D&A
32	NWNWNE 12-19S-24E	Frank B Adams Federal 12-1	04/21/80	2206	Morrison	3252d --	--	--	D&A
33	CSENE 14-19S-24E	Texota Oil D Federal 1	12/23/55	2605	Entrada	2987 2127	--	--	D&A
34	SWSWNE 22-19S-24E	Frank B Adams Federal 22-1	01/22/82	3165	Entrada	2642 1832	--	--	D&A
35	SENENE 26-19S-24E	Frank B Adams Federal 26-1	03/26/80	2405	Entrada	3176d 2297d	--	--	D&A
36	SENENE 27-19S-24E	Frank B Adams Adams 27-1	09/13/79	3703	Precambrian Precambrian at	2834d 1970d 1009d	--	--	D&A
37	CNENE 03-19S-25E	G. C. Elmer Federal 1	09/01/62	102	Mancos	-- --	--	--	D&A
38	SWNWSW 03-19S-25E	Lansdale A Lansdale-Govt 4	06/13/68	1000	Entrada	surf. 4085d	Entrada	0 0 0	D&A
39	SWNWNW 03-19S-25E	Lansdale A Lansdale-Govt 3-30-A	08/19/75	1200	Entrada	surf. 3997	--	--	D&A
40	CENENE 04-19S-25E	Home Oil Henry 1	00/00/31	1000	Entrada	surf. ?	--	--	D&A
41	CENWSE 04-19S-25E	Lansdale A Govt 9	04/03/68	990	Entrada	surf. ?	--	--	D&A
42	CENENE 04-19S-25E	Home Oil Henry 1	08/18/24	802	Morrison	surf. --	Morrison	0 0 0	Gas A-1925
43	CSNESE 04-19S-25E	Fallgren & Weightman Henry 2	05/03/26	1675	Wingate	surf. 4086d	--	--	D&A-G
44	NESENE 04-19S-25E	Lansdale A Govt 13	06/04/68	1820	Precambrian Precambrian at	surf. 4095 3197d	Entrada	0 0 0	Gas A-1988
45	SWNENW 06-19S-25E	Frank B. Adams Federal 6-1	06/29/80	2066	Entrada	3612d 2870d	--	--	D&A
46	CSESE 09-19S-25E	Stadia Uranium & Oil Larson-Govt 1	02/07/56	1218	Entrada	4650d 3787	--	--	D&A
47	NWNENW 10-19S-25E	Lansdale A Lansdale-Govt 5	05/02/68	1170	Entrada	surf. 3997d	--	--	D&A
48	NWNESW 10-19S-25E	Lansdale A Lansdale-Govt 10-31-A	08/10/75	706	Summerville	surf. --	--	--	D&A
49	NWNWNE 29-19S-25E	E. J. Anderson Federal 47-29	03/22/56	927	Morrison	4156 --	--	--	D&A
50	CSWNW 30-19S-25E	Texota Oil Federal 1-C	12/23/55	1955	Entrada	3610 2731	--	--	D&A

Table 2.
Analysis of coal seams in the Dakota Sandstone (from Jackson, 1983).

	Range	Average
Btu/lb	3,000-9,000	5,500
Ash	20-80%	54%
Moisture	4-22%	14%
Sulfur	0.15-0.88%	0.44%
Carbon	6-32%	18%
Hydrogen	1.3-3.8%	2.4%
Nitrogen	0.2-0.6%	0.4%
Oxygen	3.3-26%	10.6%

Gravel and Road Fill

Pediment-mantle deposits in the quadrangle are an important source of fill and gravel for railroad and highway construction. The base for the 19th-century railroad that crossed the quadrangle was constructed of pediment materials. U.S. Highway 6 and 50, Interstate 70, and graded gravel roads were also constructed using fill material from the pediments.

The Utah State Department of Highways (undated publication) tested a pit in section 20, T. 19 S., R. 25 E., yielding the results shown in table 3.

These deposits in the quadrangle are mostly sand and silt with sandstone, dense oolitic and algal limestone, and a small percentage of chert clasts. No estimates have been made of the volume available in the quadrangle but deposits are up to 100 feet (30 m) thick, and average 20 to 40 feet (6-12 m) thick. They are thickest in the northern part of the quadrangle and thin toward the south.

WATER RESOURCES

The Harley Dome quadrangle receives 6 to 8 inches (15-20 cm) of precipitation a year (Waddell and others, 1981). It is crossed by one perennial stream, Westwater Creek, and the Colorado River passes about 2 miles (3.2 km) southeast of the southeast quadrangle corner. Sulphur Creek, a tributary of Westwater Creek, and Bryson Wash are ephemeral streams in the quadrangle. A few alkali-rich seeps issue from sandy horizons in the Mancos Shale.

As much as 16 to 20 inches (40-50 cm) of precipitation falls in the Book Cliffs to the north, which are watersheds of washes that cross the quadrangle. However, most precipitation is short-duration, torrential, summer storms resulting in flash floods. Much of the remaining precipitation sinks into porous sandstone bedrock and flows northward toward the Uinta Basin, through northward-dipping subsurface strata. Thus, except for Westwater Creek, washes are dry most of the time. Waddell and others (1981) estimated average annual discharge on Westwater Creek at 5,900 acre-feet (7,300,000 m^3) per year and on Sulphur Creek, an ephemeral tributary of Westwater Creek, at 2,200 acre-feet (2,700,000 m^3) per year at sites upstream from the quadrangle.

Water has been reported in numerous oil and gas wells in the quadrangle. All aquifers are sandstones and sandy siltstone and shale in underlying Mesozoic bedrock. No significant aquifers exist in surficial deposits.

GEOLOGIC HAZARDS

Geologic hazards of main concern in the Harley Dome quadrangle are expansive rock and soil, and flash flooding. Damage to roads is of most concern since the quadrangle contains only two houses, which are inhabited intermittently. Clay- and evaporite-mineral-bearing-rock (mostly gypsum) and soils, which expand and contract as they absorb and lose moisture, and flow when loaded, cause problems for construction and road maintenance. The Mancos Shale and, to a lesser extent, parts of the Cedar Mountain and Dakota Formations all contain expansive clays. Large dips and swells in older roads constructed across the Mancos Shale attest to this problem. Even Interstate 70, with a thick fill base, experiences problems with expansive foundation materials.

Westwater Creek, Sulphur Creek, and Bryson Wash all drain large basins, and may produce flash floods during late summer thunder storms. After large storms, which normally occur a few times a year, Westwater Creek is as much as 10 feet (3 m) deep for a few hours, whereas normally it is only one to two inches (2.5-5 cm) deep.

Topographic relief is low and risk from landslides and rock falls is limited to small areas. Rock falls and small landslides could develop along ledges and steep slopes in outcrops of the Dakota Sandstone in the southeastern corner of the quadrangle, and along erosional scarps at the edges of pediments. There have been landslides in the area at locations where clay and mudstone in inclined beds of the Dakota Sandstone act as a glide plane, but none were found in the quadrangle.

The quadrangle is in the middle of the Colorado Plateau, a region of small- to moderate-magnitude earthquakes with a low to moderate recurrence interval (Wong and Humphrey, 1989). Earthquakes greater than magnitude 4 (large enough to be felt) are rare in the region, and the quadrangle is far from any known Quaternary faults (Arabasz and others, 1979; Hecker, 1993). The largest historical earthquake in Utah within 60 miles (100 km) occurred in 1953 near Green River (39°00'N., 110°10'W.) and was a magnitude 4.3. The quadrangle is in Uniform Building Code zone one, indicating low potential for earthquake damage (International Conference of Building Officials, 1991).

Eolian deposits are common and attest to occasional summer dust and sand storms that may affect highways and roads. No active dunes exist, but unstable eolian deposits are present in the southeastern part of the quadrangle.

Table 3.
Analyses of a gravel pit in section 20, T. 19 S., R. 25 E. from Utah State Department of Highways (undated publication - about 1966).

- size before crushing -- 11% greater than one inch (2.5 cm), 0% greater than 3 inch (7.5 cm)
- percent passing through a sieve after crushing to 1 inch (2.5 cm) maximum size:

1 inch (2.5 cm) sieve	100%
1/2" (1.3 cm) sieve	77%
no. 4 sieve	53%
no. 8 sieve	45%
no. 50 sieve	31%
no. 200 screen	17%

- liquid limit -- 17.5
- nonplastic
- swell -- 0.002
- abrasion (500 rev) -- 31.4
- A.A.S.H.O. classification -- A1b

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