OPEN-FILE REPORT 01-02

Geologic Map of the Gibson Gulch Quadrangle, Garfield County, Colorado

Description of Map Units, Structural Geology, Geologic Hazards, Economic Geology, and References

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FOREWORD

The Colorado Department of Natural Resources is pleased to present the Colorado Geological Survey Open File Report 01-2, *Geologic Map of the Gibson Gulch Quadrangle, Garfield County, Colorado.* Its purpose is to describe the geologic setting and mineral resource potential of this 7.5-minute quadrangle located west of Glenwood Springs. Richard F. Madole, and Randall K. Struefert, consultants, completed the field work on this project in the summer of 2000.

This mapping project was funded jointly by the U.S. Geological Survey through the STATEMAP component of the National Cooperative Geologic Mapping Program which is authorized by the National Geologic Mapping Act of 1997, Agreement No. 00HQAG0119, and the Colorado Geological Survey using the Colorado Department of Natural Resources Severance Tax Operational Funds. The CGS matching funds come from the Severance Tax paid on the production of natural gas, oil, coal, and metals.

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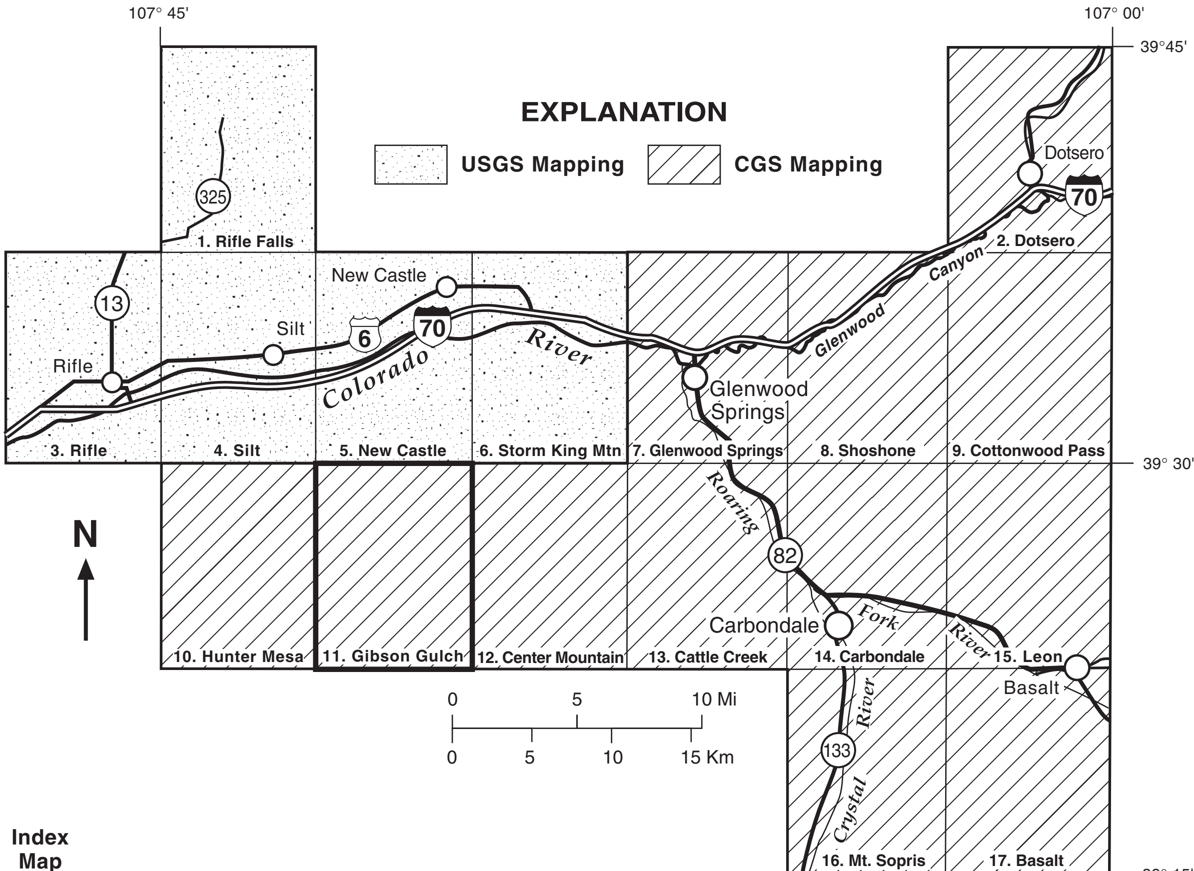
Index to 1:24,000 Geologic Mapping in Vicinity of Gibson Gulch Quadrangle



Area index of 1:24,000 geologic mapping

Index Map No.	
1	USGS, MF-2341 (Scott, R.B., Shroba, R.R., and Egger, A.E., in press)
2	CGS, OF 97-2 (Streufert, R.K., Kirkham R.M., Schroeder, T.J., II, and Widmann, B.L., 1997)
3	USGS, OF 97-852 revised preliminary map, (Shroba, R.R., and Scott, R.B., 1997)
4	USGS, MF-2331 (Shroba, R.R., Scott, R.B., 2001)
5	USGS, OF 97-737 revised map (Scott, R.B., Shroba, R.R., 1997)
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INTRODUCTION

The Gibson Gulch 7.5-minute quadrangle is in the easternmost part of the Colorado Plateau physiographic province (Fenneman, 1931) near its boundary with the Southern Rocky Mountains. In this area, that boundary coincides with the Grand Hogback monocline. The north margin of the quadrangle is a few miles south of the Colorado River, about midway between the towns of Glenwood Springs and Rifle (Figure 1). The terrain in this area is rugged; topographic relief in the quadrangle is a little more than 4,000 ft. Altitudes range from about 5,670 ft where Divide Creek leaves the area, near the northwest corner of the quadrangle, to about 9,700 ft near the southeast corner of the quadrangle. The major valleys are deep and have narrow floors. Because of the high relief, climate and natural vegetation vary widely. The climate is semiarid in the northern and westernmost parts of the map area, and subhumid at altitudes higher than 8,000 ft in the southeastern part of the map area. Piñon pine-juniper woodland is the most extensive ecosystem in the quadrangle. It is on uplands and slopes of all aspects in most of the northern half of the map area and, except on north-facing slopes at altitudes higher than 6,600 ft, it is the principal plant community at altitudes as high as 7,200 ft. On dry sites and some south-facing slopes, it extends as high as 7,800 ft. Generally, dense stands of mountain shrubs, chiefly Gambel oak, cover most north- and northwest-facing slopes at altitudes between about 6,600 and 8,500 ft. Aspen forest is the dominant ecosystem in the

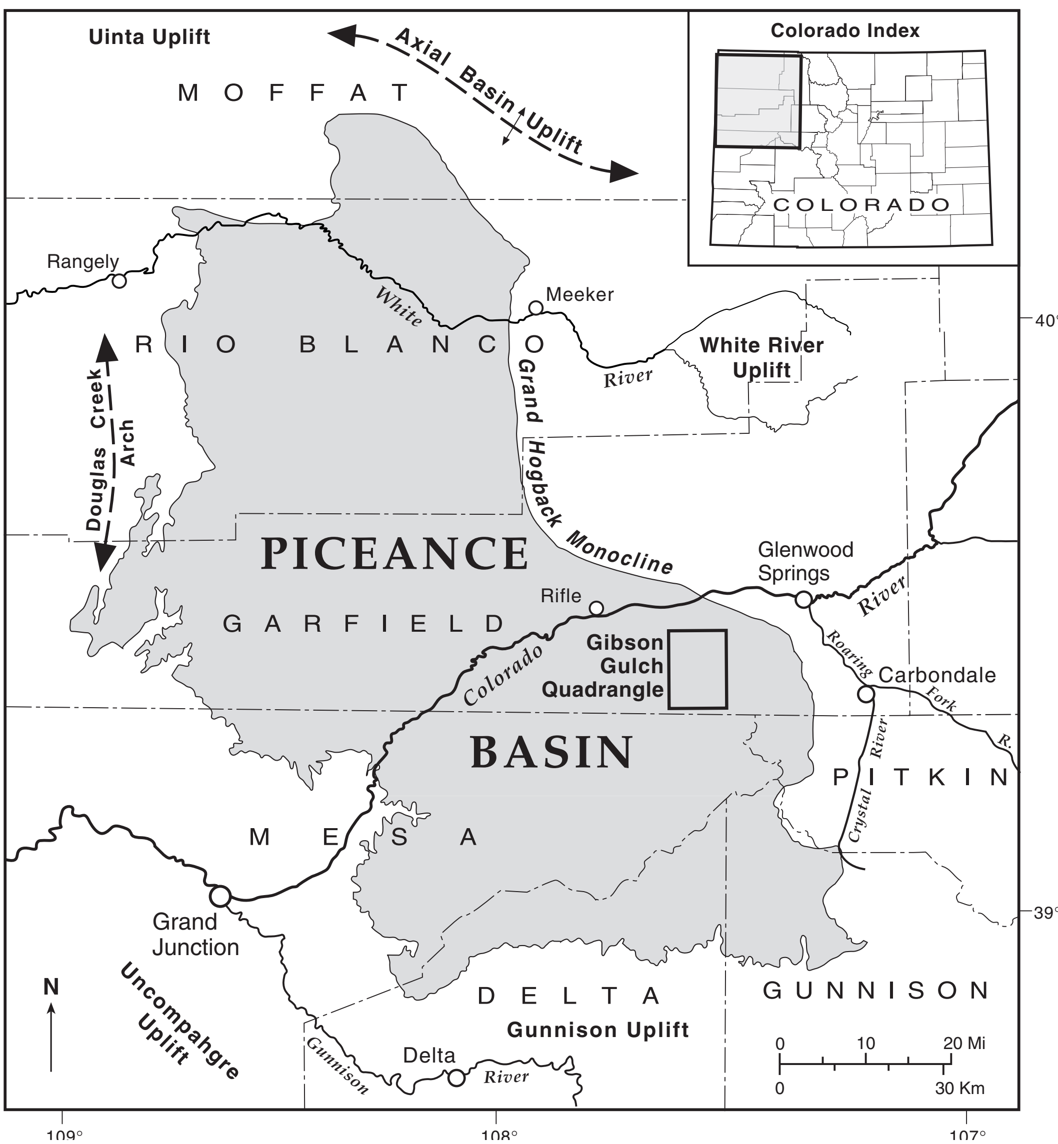

Figure 1. Map showing the location of the Gibson Gulch quadrangle, the Piceance Basin, and the uplifts that bound the Piceance Basin. Modified from Hemborg (1993).

PREVIOUS GEOLOGIC MAPPING

southeastern part of the map area. Large-scale (1:24,000 or larger) geologic mapping has not been done previously in the Gibson Gulch quadrangle, although both the Colorado Geological Survey and U.S. Geological Survey have mapped adjacent 1:24,000-scale quadrangles. Tweto and others (1978) and Ellis and Freeman (1984) compiled reconnaissance maps at scales of 1:250,000 and 1:100,000, respectively, that include the Gibson Gulch area. However, their maps emphasized bedrock geology and, except for showing a few of the largest areas of surficial deposits, they provide little information about the surficial geology.

GEOLOGIC SETTING

The Gibson Gulch quadrangle is near the southeast margin of the Piceance basin, an elongate northwest-southeast downwarp bounded by uplifts on all sides (Figure 1). The basin was formed and filled with sediment several thousand feet thick during the Laramide orogeny, which occurred between about 70 and 45 million years ago (Tweto, 1975). Only two bedrock units are exposed in the Gibson Gulch quadrangle, the Wasatch Formation (Paleocene and Eocene) and the uppermost part of the Mesaverde Group (Upper Cretaceous). The Wasatch Formation is at the surface or it underlies surficial deposits in most of the quadrangle. Rocks of the uppermost part of the Mesaverde Group are exposed only along the crest of the Divide Creek anticline, near the south boundary of the quadrangle.

The upper part of the Wasatch Formation has been removed by erosion in much of the map area and, of course, the formation has been stripped entirely where rocks of the Mesaverde Group are at the surface. The Wasatch Formation is 3,400–5,200 ft thick in sections measured near the eastern margin of the Piceance basin (Hemborg, 1993) and more than 6,000 feet thick, according to geophysical logs of gas and oil wells, within the basin (Snow, 1970). Sediment of the Wasatch Formation was deposited during Laramide time, mainly from the White River uplift and the Sawatch uplift (Tweto, 1975), which are north and east of the map area. The sediment was deposited in a nonmarine, low-relief, fluvial environment. West of the map area, Donnell (1969) and Hail and Smith (1997) divided the Wasatch Formation into three members. Donnell's three members also were mapped in the New Castle and Silt quadrangles (Scott and Shroba, 1997, and Shroba and Scott, 2001), which adjoin the map area on the north and northwest, respectively. Also, Shroba and Scott (1997) mapped three members in the Rifle quadrangle. A similar division of Wasatch Formation was not practical in the Gibson Gulch quadrangle because the formation is poorly exposed.

Surficial deposits mantle about two thirds of the Gibson Gulch quadrangle. In this area, climate and vegetation strongly influence the nature and distribution of surficial deposits. The kind and density of natural vegetation reflect differences in local climate that are controlled primarily by altitude and aspect (direction a slope faces with respect to a compass and rays of the sun). The contrast between north-facing and south-facing slopes is striking. On south-facing slopes below an altitude of about 9,000 ft, bedrock is at or close to the surface in most places; slopes typically are steep, sparsely vegetated, and carved by relatively deep gullies. On north-facing slopes at altitudes above about 6,500 ft, surficial deposits conceal bedrock in most places and generally support dense vegetation. North-facing slopes are not as steep as south-facing slopes, and they are drained by fewer and shallower gullies.

Landslide deposits are particularly extensive on north-facing slopes and they also are common on northwest- and west-facing slopes, whereas deposits produced by sheet erosion and flash floods are much more prevalent on south- and southeast-facing slopes. Bare ground (surficial materials that have no vegetation on them) is extensive in most areas of the piñon pine-juniper woodland and also in areas of sagebrush shrubland. Consequently, sheetwash alluvium is widespread on footslopes in areas where those plant communities are dominant, particularly in the northern and westernmost parts of the map area.

Some of the aspect-related differences in slope angles and deposits in the Gibson Gulch quadrangle probably are products of Pleistocene climate. During the last glaciation, the boundary between subalpine forest and alpine tundra on the western slopes of the Southern Rocky Mountains was as much as 1,000-2,300 feet lower than it is today (Fall, 1997). Therefore, summits in the southeastern part of the quadrangle may have been above timberline, and gelifluction (flow of thawed soil over a frozen substrate) probably occurred on north-facing slopes in much of the quadrangle.

Harman and Murray (1985) described the soils in the Rifle area, which includes the Gibson Gulch quadrangle. Most of the soils in the Gibson Gulch quadrangle are Mollisols (soils characterized by thick, dark-brown to black, surface horizons overlying a B horizon) and Aridisols (dry-land soils characterized by surface horizons that are not significantly darkened by humus, overlying a B horizon) developed in parent materials of Pleistocene age. Aridisols are primarily in the lowlands and on adjacent footslopes in the northwestern and westernmost parts of the quadrangle, whereas Mollisols are predominant in most of the shrub- and forest-covered upland areas. Entisols (young, weakly developed soils that lack B horizons) are present on slopes that are subject to episodic sheet erosion, and they also are developed in Holocene alluvium and colluvium.

Soil data were considered in assessing the genesis and characteristics of the surficial deposits. However, except for the Ascalon, Olney, Potts, and Vale soils, most soil series are not related solely to specific geologic units. The Rifle area soil map (Harman and Murray, 1985) was used to determine the distribution of loess in the southwestern part of the map area. Loess is the material in which soils of the Vale series are developed. On Hunter Mesa, in the quadrangle west of the map area (Madole, 1999), stratigraphic relations indicate that soils of the Potts series in that area also are developed in eolian sediment. The parent material in extensive areas of Potts soils in the northwestern part of the Gibson Gulch quadrangle probably is the same origin and age as that on Hunter Mesa. The Ascalon and Olney soil series, both of which are sandy, commonly are developed in deposits of sheetwash alluvium.

METHODS AND TERMINOLOGY

A pocket stereoscope was used to delineate map units on aerial photographs while in the field. Later, photogrammetric models of the annotated aerial photographs were set on a Kern PG-2 plotter and map-unit contacts were transferred to a topographic map of the Gibson Gulch quadrangle. Airphoto interpretation of geologic data relied heavily on relationships among landforms, materials, and interpreted past and present geomorphic processes, as well as relationships between vegetation and geology. Interpretations based on stereoscopic examination of airphotos were verified in places on the ground and were supplemented with data collected along traverses and by intensive field work in selected areas.

The scale of the base map and aerial photographs (about 1:24,000) governed the minimum size of the deposits shown. With a few exceptions, deposits that have a width or minimum dimension of less than 150 ft or a maximum thickness of less than 5 ft were not mapped. The cultural features of the topographic base map were photorevised in 1987, and the aerial photography used for geologic mapping was flown in late September and early October in 1978. Roads, reservoirs, and buildings that were constructed after 1987 are not on the map base, and human-made deposits that postdate the aerial photography may not be on the map.

The bedrock units in the map area are known by formal stratigraphic names, but the names of all surficial units are informal. Surficial deposits are grouped according to genesis, and individual map units within groups are named either for the landform with which they are associated or the material of which they are composed. To the extent feasible, the unit names and symbols used for surficial deposits are those used on published maps of nearby areas prepared by the Colorado Geological Survey and the U.S. Geological Survey (see index on map).

Most of the deposits and materials mapped are not well exposed. Therefore, the thickness of several map units is estimated and descriptions of physical characteristics such as texture, stratification, and composition are based on observations at a small number of localities. Texture refers to the characteristics of individual particles and the grain-to-grain relations among particles (Krumbein and Sloss, 1963). Particle characteristics include size, sorting (a measure of the range in particle sizes present), shape (sphericity), and roundness. Particle size is expressed here in terms of the modified Wentworth scale (Ingram, 1989), and the terms used to describe sorting are those of Folk and Ward (1957). Unit colors for which hue, chroma, and value are listed were determined using Munsell Soil Color charts (Munsell Color, 1973). The colors listed are for dry materials only.

Except for windblown deposits, all surficial deposits in the map area are poorly sorted to extremely poorly sorted. Particle shape (sphericity) and roundness are also similar in most deposits. Spherical and well-rounded particles are uncommon, and the roundness of most clasts ranges from angular to subrounded. Clast here refers to rock fragments larger than 2 mm, and matrix refers to grains that are 2 mm or smaller in size. Gravel is defined as rock fragments that are more or less rounded and larger than 2 mm in diameter. In the modified Wentworth scale, gravel includes pebbles, cobbles, and boulders, and matrix is the sand-, silt-, and clay-size particle fraction. By definition, pebbles and cobbles are somewhat rounded and waterworn, or otherwise modified by abrasion due to transport. Therefore, platy or angular to subangular clasts that range in size from $\frac{1}{6}$ to 10 in. and that have not been transported far, if at all, are referred to as pebble-size or cobble-size clasts.

Deposits in which gravel is an important constituent are referred to as either clast-supported or matrix-supported. In clast-supported gravel, clasts (rock fragments) are the dominant constituent and are mostly in point contact. In matrix-supported gravel, material smaller than 2 mm (sand, silt, and clay) is the dominant constituent. Most clasts are not in point contact, but are surrounded by matrix. Thus, they appear to be embedded in or supported by matrix.

The geochronology of the Pleistocene Epoch, especially the age of the older boundary, has been debated for decades. The debate has been driven in part by a desire to link the boundaries of the Pleistocene Epoch to global cooling and glaciations that were a prominent part of earth history during that time interval. However, glaciation was not considered in the original definition of the Pleistocene (Farrand, 1990), and global cooling and glaciation began long before the beginning of the Pleistocene. The sidereal age limits used here for informal subdivisions of the Pleistocene correspond to those of Fullerton and others (in press), and to a lesser degree with those of Morrison (1991). The limits adopted for early, middle, and late Pleistocene time are 1806–778 ka (kilo-annum, 10^3 year), 778–128 ka, and 128–11.5 ka, respectively. The date for the Pliocene–Pleistocene boundary (1.806 million year) is the astronomically tuned age calculated by Lourens and others (1996).

DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSITS

HUMAN-MADE DEPOSITS—Earth materials emplaced or modified by human beings or deposited as a consequence of human activities.

af **Artificial fill (upper Holocene)—**Sand, silt, clay, and rock debris emplaced for road beds and embankments, earthen dams, and drilling pads for gas and oil wells. Locally, includes areas where fill was excavated as well as deposited. Unit is 3-25 ft thick.

ALLUVIAL DEPOSITS—Sand, silt, gravel, and clay transported and deposited by flowing water either in stream channels or as unconfined runoff or sheet flow. Deposits resulting from sheet flow are referred to here as sheetwash alluvium. Sheetwash alluvium is mainly in sheets and wedges along footslopes of valley sides, on benches, and in hollows on hillsides. Sheetwash alluvium and alluvium deposited by streams are differentiated where map scale permits. Stream alluvium is the principal deposit underlying flood plains and stream terraces. As used here, flood plain refers only to the flat area adjacent to the stream channel that was constructed by the stream in the present climate and that is flooded frequently (Dunne and Leopold, 1978). Areas with only a 1–2 percent chance of being flooded in any given year (100- and 50-year floods) are not part of the flood plain.

Qa_2 **Younger valley-floor alluvium (upper Holocene)—**Chiefly very pale brown (10YR 7/3, 7/4) to brown (10YR 5/3), poorly sorted sand, sandy silt, and minor clast-supported pebble gravel. It is in channels and it underlies narrow flood plains and remnants of terraces that are only 1–3 ft higher than the flood plains. Clayey sediment (defined as sediment that contains more than 20 percent clay by weight; Shepard, 1954) is present, but it is minor compared to sandy and silty sediment. Alluvium borders most streams, but it is wide enough to show on the map only in the larger valleys. Areas of Qa_2 are subject to frequent flooding. Exposed thickness is 3–10 ft.

Qa_1 **Older valley-floor alluvium (upper Holocene)—**Sediment is similar to that of the younger valley-floor alluvium (Qa_2). The older alluvium underlies terrace remnants 5–10 ft higher than streams. In deep, narrow valleys, the alluvium generally is poorly preserved, and much of what remains is concealed by Qac and Qc. In places, large floods (those with recurrence intervals on the order of 1–4 times per 100 year) may inundate the older valley-floor alluvium. Estimated thickness is 10–20 ft.

Qau **Alluvium, undivided (Holocene and upper Pleistocene)—**Chiefly very pale-brown (10YR 7/3, 7/4) to brown (10YR 5/3), poorly sorted sand, sandy silt, lenses and thin beds of gravel, and clayey sediment. The alluvium fills upland valleys and it has not been exhumed or incised deeply during the late Holocene, except locally in lowermost Gibson Gulch and East Gulch. Unit includes sediment that is correlative with units Qa_2 and Qa_1, and it includes alluvium of late Pleistocene age. Estimated thickness is 3-40 ft.

Qsw **Sheetwash alluvium (Holocene and upper Pleistocene)—**Chiefly very pale-brown, brown, and light-yellowish-brown (10YR 7/3, 7/4, 6/3, 6/4; 7.5YR 6/4) poorly sorted to extremely poorly sorted sand, silty sand, sandy silt, clayey silt, and minor pebble- and cobble-size rock fragments. The sediment was transported and deposited principally by sheet flow. Sheetwash alluvium generally slopes toward the nearest stream or arroyo and has a longitudinal surface profile that is concave-upward. Most of the clasts in this unit are sandstone from the Wasatch Formation. Sheetwash alluvium is abundant and widespread in the map area due to a combination of (1) extensive areas of bare ground, (2) much easily eroded bedrock and (3) runoff from frequent thunderstorms and from snowmelt. The unit is particularly extensive along the footslopes of valley sides and below escarpments. Smaller areas also are on benches and hollows on slopes. Mass-wasting processes formed many of the hollows and, consequently, sheetwash alluvium may overlie or interfinger with other units. In places, Qsw is loess that was eroded and redeposited by sheet flow. Sheetwash alluvium derived from loess is particularly common on the lower parts of west-facing slopes in the westernmost part of the map area. Where deeply incised by arroyos or gullies, the unit may be subject to piping (see section on geologic hazards). Unit is estimated to be 3–40 ft thick.

Qty

Younger terrace deposits (upper Pleistocene)—Chiefly pale-brown to brown, very poorly sorted sand and silty sand and beds and lenses of fine to coarse gravel underlying terrace remnants 20–40 ft higher than streams. Unit is mapped in only a few places, mainly along tributaries of East Divide Creek that drain south-facing slopes. Gravel consists primarily of basaltic rock and sandstone fragments. Estimated thickness is 20–40 ft.

Qto

Older terrace deposits (middle Pleistocene)—Chiefly extremely poorly sorted pebble, cobble, and boulder gravel underlying the most continuous and widespread terrace in the map area. Owing to a scarcity of exposures, little is known about the physical properties of these deposits, other than that the gravel contains abundant clasts of basaltic rock and some clasts of sandstone. The terrace is 100–140 ft higher than Divide Creek and 40–100 ft higher than East Divide Creek. In the West Divide Creek valley, it decreases upvalley from 140 ft to about 50 ft higher than the creek. Loess blankets the gravel in most places. Unit thickness is estimated to be at least 60 ft in places.

Qtt_3

Youngest high-terrace deposits (middle Pleistocene)—Extremely poorly sorted pebble, cobble, and boulder gravel underlying terrace remnants in the southwestern part of the quadrangle and capping ridges and knolls in the northwestern part of the area. No sedimentological information is available for the deposits, other than that inferred from landforms and clasts on the ground surface. The gravel surface is about 160 ft higher than Divide Creek and, in the southern part of the map area, as low as 60 ft higher than West Divide Creek. Clasts are basaltic rock and sandstone. Unit thickness is estimated to be 20–50 ft.

Qtt_2

Middle high-terrace deposits (middle Pleistocene)—Sediment similar to unit Qtt_3 capping ridges and knolls 200–260 ft higher than Divide Creek and, in the southern part of the map area, as low as 80–120 ft higher than West Divide Creek. Unit thickness is estimated to be 40–60 ft.

Qtt_1

Oldest high-terrace deposits (middle Pleistocene)— Sediment similar to unit Qtt_3 underlying a terrace 360–400 ft higher than West Divide Creek in the southern part of the map area and about 200 ft higher than Gibson Gulch in the northwestern part of the area. Sheetwash alluvium and colluvium from adjacent slopes conceal the unit in most places. Unit thickness is estimated to be 40– 80 ft.

MASS-WASTING DEPOSITS—Earth materials that were transported downslope primarily by gravity. Mass wasting differs from other modes of material transport in that the material moves as a mass rather than as individual fragments or particles borne along by a transporting medium such as wind or flowing water. Water is an important constituent of most mass movements and commonly triggers movement, but the water is part of the moving mass rather than the transporting agent. Although creep (imperceptible, gradual, progressive downslope movement of earth materials) is a form of mass wasting, material transported by creep is not mapped as a separate unit. Creep exists to some degree on most slopes, but it is slow and its contribution to the transport of surficial deposits and materials generally cannot be discerned in the field. Colluvium, landslide deposits, and block-stream deposits are the principal products of mass wasting in the Gibson Gulch quadrangle.

Colluvium, as used here, adheres in most respects to Hilgard's (1892) definition. According to Hilgard, the principal attributes of colluvium are that it (1) was derived locally and transported only short distances, (2) may contain clasts of any size, (3) has no structures indicative of sedimentation or stratification by water flowing in channels, and (4) has an areal distribution that bears no relation to channelized flow of water. Hilgard's definition allows colluvium to include a minor amount of sheetwash alluvium, whereas sheetwash alluvium is excluded in Merrill's (1897) definition of colluvium. Merrill defined colluvium as resulting wholly from "the transporting action of gravity." As used here, colluvium does not include sheetwash alluvium, except for minor amounts or deposits that are too small to map separately.

Landslide deposits mantle more than half of the Gibson Gulch quadrangle. In the terminology of Cruden and Varnes (1996), they were produced mainly by (1) translational earth slides, (2) complex translational earth slides—debris flows, and (3) complex rotational earth slides—earth flows (Figure 2). The Cruden and Varnes (1996) classification of landslides uses dashes to link different types of movement that occurred in individual landslides. They add the term "complex" to the landslide-process name when the slide involved two or more types of movement that occurred in succession rather than simultaneously. Slope failures that involve two or more types of movements that occur simultaneously are termed "composite."

The translational landslides are shallow; most failure surfaces probably were between 3 and 15 ft below the ground surface. Translational landslides are most common in the east-central and central parts of the map area. Most failures originate on steep slopes, and the landslides involve regolith (all surficial material overlying coherent bedrock) of residuum or colluvium and decomposed bedrock that slid on failure surfaces that were near or on the contact between regolith and coherent bedrock. Wetting from rain or heavy snowmelt was the most likely triggering mechanism for most translational landslides. In several small valleys, particular in the east-central part of the quadrangle, translational earth slides became or contributed material to debris flows that moved onto and down valley floors. In many places, including Otten and Dean Gulches, the complexes of debris-flow deposits and valley-floor alluvium have been partly or entirely buried by younger sheetwash alluvium derived from adjacent valley walls. In narrow valleys, such as Otten and Dean Gulches, complexes of deposits derived by mass wasting, stream flow, and sheet flow are mapped as alluvium and colluvium (unit Qac).

The rotational slope failures in the map area typically are large, and the failure surfaces are deep. Most are complex failures that began as rotational earth slides that became earth flows

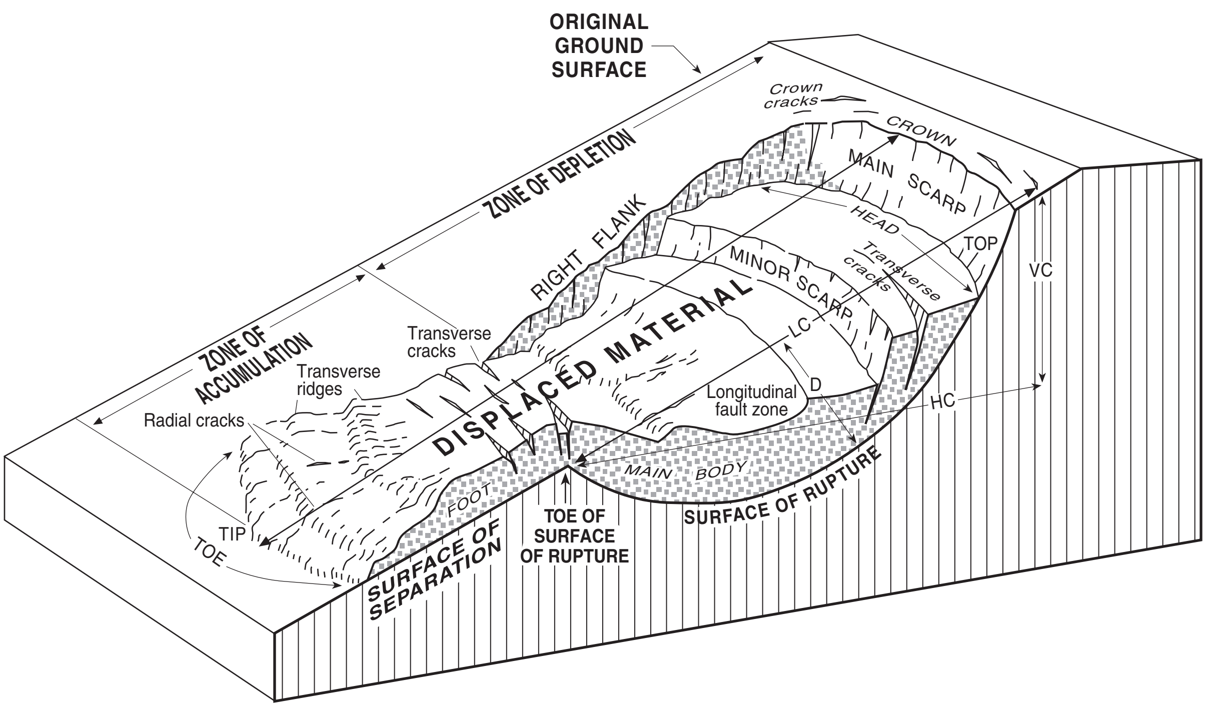

Figure 2. Diagram from Varnes (1978) showing the nomenclature used to describe landslide features. In the terminology recommended by Cruden and Varnes (1996), the diagram illustrates a complex earth slide—earth flow.

(Figure 2). Several materials were involved in the slope failures, including surficial deposits, residuum, decomposed bedrock, and weakly cemented and incompetent beds of Wasatch Formation. Most of the large rotational failures originated along the margins of gravel-capped mesas and benches in the southern half of the map area. Some rotational earth slide—earth flow failures span areas larger than a square mile.

Block streams, which are known by a variety of other names including stone runs (Andersson, 1906) and rubble streams (Richmond, 1962), are linear concentrations of rock debris, commonly dominated by boulder-size material, that generally is devoid of matrix, at least near the surface. Block-stream deposits are much longer than they are wide, and they mantle valley floors or fill gullies on steep slopes. Block-stream deposits are common in alpine and polar regions, where they are attributed to periglacial processes, chiefly gelifluction (flow over perennially frozen ground) and frost creep. In montane Colorado, block streams are particularly common in areas of alpine tundra, but they also are present in places below timberline.

Qc

Colluvium (Holocene and upper Pleistocene)—Slope deposits, chiefly pale-brown, light-yellowish-brown, and reddish-brown, very poorly sorted to extremely poorly sorted sand, silt, clay, and variable amounts of pebble- to boulder-size clasts. Unit Qc is primarily on or just below slopes that range between about 15° and 35°. In places, unit Qc probably includes old landslide deposits that have been modified by erosion and creep to the extent that their slope-failure origin is difficult to recognize. A veneer of basaltic boulder colluvium is common on slopes below uplands that are capped by basaltic boulder gravel. However, where slopes are steeper than about 20°, the colluvial veneer generally is less than 3 ft thick and, thus, is not shown on the map. Unit typically is 3–10 ft thick, but may be as thick as 30 ft in places.

Qco

Older colluvium (middle and lower Pleistocene)—Large (3–6 ft in maximum dimension), widely scattered basaltic boulders, and variable amounts of pebbles, cobbles, and small boulders of basaltic rock and sandstone in a matrix of brown to reddish-brown, very poorly sorted to extremely poorly sorted sand, silt, and clay. These deposits may be remnants of old landslides or they may be products of frost heave and creep. Some deposits probably were derived from deposits of Tbg. Others are topographically too high in the landscape to have been derived from existing uplands, and some are far from remnants of unit Tbg_2 or other obvious sources of basaltic rock. Unit thickness is estimated to be 5–40 ft.

Qls

Landslide deposits (Holocene and upper Pleistocene)—Nonsorted, heterogeneous mixtures of surficial materials and fragmented rock debris in a wide range of particle sizes. Clast lithologies and the texture of the matrix vary, reflecting the properties of the bedrock units involved in the slide. In places, unit Qls may include extensive tracts of material that was emplaced by solifluction and frost creep rather than by landsliding. This is particularly true on the north-facing slopes of Gibson Gulch and East Gulch, and also on slopes underlain by rocks of the Mesaverde Group on the west flank of the Divide Creek anticline. Diagnostic landforms are not associated with the surficial materials in these areas. Consequently, it is difficult to distinguish among (1) materials emplaced by slow mass movement, (2) translational landslide deposits, and (3) old landslide deposits whose topographic expression has been modified by erosion and creep. Landslide deposits that contain abundant blocks of durable rock, such as sandstone, tend to have a more pronounced topographic expression and to retain that topography longer than those that consist of fine-grained, weakly indurated rock, such as claystone and siltstone. Unit Qls includes areas of exposed bedrock in slide paths and in scarps at the heads of slides, as well as the material deposited in the lower part of the slide area or zone of accumulation (Figure 2). Also, the unit includes deposits that vary widely in age; most are thousands of years old, but some are less than 100 years old. Some of the youngest landslides are (1) on the north-facing slopes of Crown Peak, (2) in Otten Gulch and Jackson Gulch, and (3) on the flanks of the high mesas capped by units Qbg_1 and Qbg_2 in the northeastern part of the map area. Most young landslides are easily identified by the absence of vegetation in their slide paths. The same can not be said, however, for slightly older historic slides whose paths have been reoccupied by vegetation. A variety of human activities, including some that may seem minor, can reactivate slope failure on landslide deposits, regardless of their age (see section on geologic hazards). Unit thickness is estimated to range from 3 to at least 200 ft.

Qbs **Block-stream deposits (upper Pleistocene)—**Linear deposits of basaltic boulders on the floor and in gullies on the east valley wall of upper Clear Creek in the southeastern part of the map area. The deposits are devoid of matrix, at least in the upper 3–5 ft. The boulders vary in size; the maximum dimension is about 6 ft. Unit thickness is estimated to be 5–20 ft.

ALLUVIAL AND COLLUVIAL DEPOSITS—Deposits contain major amounts of material of both alluvial and colluvial origin. Deposits of alluvial origin and deposits of colluvial origin are mapped together because (1) they are interbedded, as in debris fans, (2) they are juxtaposed but are too small to show individually, or (3) they are interspersed and large enough to show separately, but have contacts that are not clearly defined. Also included in this category are deposits of basaltic gravel (Qbg_3, Qbg_2, Qbg_1, Qbg, and Tbg) that are similar to terrace deposits Qto and Qtt, except that they contain even larger boulders, cap high benches and mesas, and generally slope more steeply than typical fluvial deposits. No sedimentological information is available for deposits of Qbg, QTbg, and Tbg beyond what is inferred from landforms and from clasts on the ground surface. The steeper slopes and the wide distribution of large boulders (many 3–6 ft in maximum dimension) on the surfaces of11 QTbg, and Tbg suggest that debris flows played a role in their genesis. Likewise, well-rounded cobbles and pebbles of basaltic rock, some sandstone, and minor amounts of chert are abundant, suggesting that these units also contain fluvial gravel.

Units Qbg, QTbg, and Tbg are differentiated solely on the basis of their height above stream level or their height above projected levels of unit Qbg_2, the highest deposit in the landscape that contains fluvial sediment and parallels a present-day valley. These units are remnants of ancient valley fills that have become inverted and now cap some of the highest bedrock surfaces in the landscape. Topographic inversion occurred because the coarse valley fill was more resistant to erosion than the bedrock of the former valley walls.

Qac **Alluvium and colluvium, undivided (Holocene and upper Pleistocene)—**Chiefly pale-brown to reddish-brown, extremely poorly sorted sand, silt, clay, and pebble- to boulder-size rock fragments that were transported and deposited by sheet flow or mass movement, or by both processes. Colluvium generally is subordinate to alluvium in areas where slopes are less than 15º. In places, this unit may be subject to flooding and debris flows. Unit is estimated to be 3–30 ft thick.

Qaco **Older alluvium and colluvium, undivided (upper and middle Pleistocene)—**Sheets and lobes of extremely poorly sorted clast- and matrix-supported gravel deposited by streams and debris flows that coalesced along the footslopes of the upland south of East Divide Creek in the east-central part of the quadrangle. Gravel consists of angular to subrounded clasts of basaltic rock and sandstone, ranging in size from pebbles to boulders, in a matrix of sand, silt, and clay. Estimated thickness is 5–40 ft.

Qdf **Debris-fan deposits (Holocene)—**Extremely poorly sorted clast- and matrix-supported gravel and beds and lenses of fine-grained (< 2 mm) sediment in fan-shaped deposits at the mouths of steep, first- and second-order drainage basins. Clasts range from pebbles to boulders, and they are mostly subangular to subrounded. The matrix is chiefly sand and clayey silt. These deposits are primarily products of flash floods, debris flows, and snowmelt runoff, processes that are ongoing and potentially hazardous to human-made structures placed on or in this unit. Estimated thickness is 5–40 ft.

Qbg_3 **Youngest basaltic boulder gravel (middle or lower Pleistocene)—**Chiefly bedded, extremely poorly sorted pebble, cobble, and boulder gravel capping high, butte-like summits. Most deposits are 580 to 720 ft higher than East Divide and West Divide Creeks and about 400 ft higher than Gibson Gulch. Clasts are basaltic rock and sandstone. Unit thickness is estimated to be as much as 60 ft.

Qbg$_2$ **Middle basaltic boulder gravel (lower Pleistocene)—**Deposits are similar to those of unit Qbg$_3$. Gravel underlies a terrace about 1,000 ft higher than West Divide Creek and it also caps a linear, gently sloping mesa (inverted paleochannel) about 1,000 ft higher than Garfield Creek, which is in the New Castle quadrangle just north of the map area. Unit thickness is estimated to be 60–120 ft.

Qbg$_1$ **Oldest basaltic boulder gravel (lower Pleistocene)—**Deposits are similar to those of unit Qbg$_3$. Gravel blankets mesas in the northeastern and west-central parts of the map area and it also caps a ridge in the south-central part of the map area, the crest of which is about 160 ft higher than the projected level of the upper surface of unit Qbg$_2$. In the northeastern part of the map area, the upper surface of unit Qbg$_2$ at its eastern end appears to be at least 100–200 ft lower than the basal contact of the north end of a deposit of Qbg$_1$. A dense cover of mountain shrubs in this area makes it difficult to identify the basal contacts of the basaltic gravels with certainty. Unit thickness is estimated to be 50–80 ft.

QTbg **Younger high boulder gravel (lower Pleistocene or upper Pliocene)—**Deposits and landforms are similar to those of units of Qbg. Gravel caps mesas in the southwestern part of the quadrangle, about 360 ft higher than the projected level of unit Qbg$_2$. The upper surface of QTbg in sections 29 and 32 is at two levels that are separated by what appears to be a stream-terrace escarpment about 20 ft high. Unit thickness is estimated to be at least 120 ft in places.

Tbg **Older high boulder gravel (Pliocene or upper Miocene)—**Deposits and landforms are similar to those of units of Qbg. Gravel caps ridges in the southeastern part of the map area that are estimated to be about 900 ft higher than the projected level of unit Qbg$_2$ and that are nearly 3,000 ft higher than West Divide Creek, 3.7 mi. to the west. Unit thickness is estimated to be 60–100 ft.

EOLIAN DEPOSITS—Wind-deposited sediment consisting mostly of silt, very fine sand, and fine sand. Windblown sediment is usually well preserved only on level to gently sloping surfaces; elsewhere it tends to have been eroded, reworked, or buried by younger deposits. In places, particularly the southwestern and westernmost parts of the map area, deposits of loess extend up west- and northwest-facing slopes from lowland areas to the west and north. Some of the loess on these slopes has been reworked by sheet erosion and is mapped as unit Qsw.

Qlo **Loess (upper and middle? Pleistocene)—**Reddish-brown, light-reddish-brown, and light-brown (5YR 5/4, 6/4; 7.5YR 6/4) sandy silt and silty fine sand deposited by wind. In many places, contacts are only approximately located because the unit lacks topographic expression and commonly it is less than 3 ft thick. The distribution of deposits in the southwest quarter of the map area is partly inferred from 1:24,000-scale soil maps (Harman and Murray, 1985). Most of unit Qlo is of late Pleistocene age, but in adjacent quadrangles (Scott and Shroba, 1997; Madole, 1999), it includes deposits of two or three different ages, the oldest of which may be middle Pleistocene. A moderately developed surface soil (A/BA/Bt/Bk/C profile) is present in the loess in most places. Loess may be prone to hydrocompaction where bulk density is low (see section on geologic hazards). Thickness is 1–7 ft in most places; locally, it is 10–20 ft.

BEDROCK

Tw **Wasatch Formation (Eocene and Paleocene) —** Claystone, mudstone, and siltstone interbedded with lenticular sandstone and conglomerate, all of nonmarine origin. Fine-grained intervals compose more than 75 percent of the formation and range in color from very light gray to light brownish gray, reddish gray, olive gray, pale reddish brown and tan. Claystones and mudstones are poorly to moderately indurated. Sandstone bodies are generally discontinuous, commonly lenticular, and are yellowish gray, light gray, and light olive gray in color. Sandstones are fine to medium grained, well sorted, and consist of quartz, feldspar, muscovite, biotite, and rock fragments. Sandstones are variably indurated due to inconsistent calcareous cementing, but tend to form subtle bench-like landforms because they are generally more resistant to erosion than the more voluminous siltstones and mudstones of the unit. The basal sandstones of the Wasatch contain some volcaniclastic material. Several identifiable units have been suggested for dividing the Wasatch Formation along the Grand Hogback Monocline in the New Castle quadrangle (Scott and Shroba, 1997), which borders the Gibson Gulch quadrangle on the north. These authors describe volcaniclastic material in the basal strata of the Wasatch and correlate these rocks with the Atwell Gulch Member of the Wasatch, which was named by Donnell (1969) and recognized in the Rifle quadrangle (see index on map) by Shroba and Scott (1997). The Wasatch Formation has not been divided in the Gibson Gulch quadrangle because of the extensive landslide cover in this area. The unit unconformably overlies the Upper Cretaceous Mesaverde Group. At Rifle Gap along the Grand Hogback Monocline to the northwest, the dip of the Wasatch Formation is 10° greater than that of the underlying Mesaverde Group (Shroba and Scott, 1997). This angular unconformity was not observed in the Gibson Gulch quadrangle. Sediment of the Wasatch Formation was deposited during Laramide time in nonmarine, predominantly low-relief fluvial and lacustrine environments from sources to the south and east of the map area (Tweto, 1975). The unit is prone to landsliding (see section on geologic hazards).

Mesaverde Group (Upper Cretaceous)

Kmvu

Upper part of the Mesaverde Group (Upper Cretaceous)—The basal 500 ft of the unit consists of shale and lenticular sandstone, siltstone, coal beds, and clinker of the Paonia Shale Member of the Williams Fork Formation. An unnamed interval above the Paonia Shale Member consists of 3,200 ft of interbedded, mostly nonmarine sandstones, siltstone, shale, and thin lenticular coal beds. In the Gibson Gulch quadrangle, only the uppermost part of the unnamed interval is exposed. It is present along the crest and southwest flank of the Divide Creek anticline. Sandstones form about 30 percent of the exposed part of the unnamed interval. The sandstones are very light gray to gray and tan, medium grained, and 3–160 ft thick. They are moderately indurated and form eroded benches and subtle topographic breaks. Unit is prone to landsliding.

Kmvl

Lower part of the Mesaverde Group (Upper Cretaceous), shown only on cross section—The unit consists of shale, sandstone, siltstone, coal, and minor thin beds of bentonite and algal limestone. It includes, from bottom to top, the Corcoran, Cozzette, and Rollins Sandstone Members of the Iles Formation, and the Bowie Shale Member of the Williams Fork Formation. The Corcoran, Cozette, and Rollins Members are thick marine sandstones interbedded with marine shale that is similar to the Mancos Shale, which is stratigraphically below the Mesa-verde Group. The Bowie Shale Member of the Williams Fork Formation is 500–600 ft thick and consists of interbedded shale and thin sandstones. The basal portion of the member includes a 90–100 ft-thick interval of coal, shale, and sandstone called the Cameo-Wheeler-Fairfield coal zone.

STRUCTURAL GEOLOGY

The axis of the Divide Creek anticline crosses the southwestern part of the Gibson Gulch quadrangle. The anticline is a broad, northwest-plunging fold with an amplitude of about 6,900 ft according to a structure contour map of the top of the Rollins Sandstone Member of the Iles Formation (Johnson, 1983). Grout and others (1991) estimated that the anticline is about 22 mi. long and a little more than 9 mi. wide and that the average dip of its limbs is about 15°. Exposures on the fold are generally scarce, and are mostly on the southwest limb. Surface attitudes along the southwest limb vary greatly and range from 43° to 8°. On the basis of surface data, the Divide Creek anticline appears to be mostly symmetrical, although the southwest limb is perhaps slightly steeper than the northeast limb. Little or no evidence of structural complexity was noted in the field, and drill-hole data indicate that the anticline is not appreciably faulted or structurally complex.

Most gas wells in the Gibson Gulch quadrangle bottom in upper Cretaceous rocks. Only four wells penetrate upper Paleozoic rocks and no wells penetrate lower Paleozoic rocks. Early maps prepared from electrical-log data show a zone of blind, northeast-dipping reverse faults that offset the contact of the Mesaverde Group and underlying Mancos Shale and continue down into the Mancos Shale beneath the crest of the Divide Creek Anticline. In addition, several small, transverse normal faults have been recognized at the surface south of the Gibson Gulch quadrangle (Grout and others, 1991). These authors suggest that the small normal faults are younger than the blind reverse faults and probably die out at shallow depths. These faults and local sets of fold-oriented joints along and parallel to the crest of the Divide Creek Anticline (Grout and Verbeek, 1992) are the only structures observable on the surface and in the near subsurface.

Several geologists have suggested that a structural complexity exists at depth that is not recognized at the surface or on structure contour maps (Grout and others, 1991; Gunnerson and others, 1995). Their hypotheses are based on interpretations of conventional and 2D/3D seismic data. Grout and others (1991) suggest two contrasting styles of deformation within two separated time frames: (1) extensional or transtensional deformation, and (2) Laramide compression. The extensional or transtensional block faulting originates in the Precambrian metamorphic basement and extends upward through Cambrian to Mississippian sedimentary rocks, then dies out in Pennsylvanian evaporites. This deformation occurred in Middle Pennsylvanian time and influenced the distribution of future sedimentation (late Paleozoic to Cenozoic), including the distribution of Pennsylvanian evaporite sub-basins that formed above faulted blocks. Later deformation is postulated to have resulted from regional compression related to the Laramide orogeny (Grout and others, 1991). Laramide compression occurred during and after the time when several thousand feet of Paleocene and Eocene sediments were deposited in the Piceance Basin (Tweto, 1980). Late in the Laramide orogeny, a large thrust wedge of crystalline and sedimentary rocks deformed the eastern margin of the Piceance Basin. The wedge is thought to have advanced southwestward and westward and to have deformed the eastern margin of the Piceance Basin into the Grand Hogback Monocline (Perry and others, 1988). Grout and others (1991) propose that the Divide Creek Anticline was produced by a decollement in thick Pennsylvanian evaporites ahead of the main thrust wedge of Perry and others (1988) and by kilometer-scale splay thrusts that cut upsection toward the Piceance Basin.

Gunneson and others (1995) offered an alternative interpretation for the Divide Creek Anticline. These authors interpreted new seismic and regional well data to develop a decapitated pop-up structure that has two detachment zones. They maintained that westward thrusting of a large block of basement rock in an area east of the Divide Creek drainage basin re-activated detachment zones in thick Pennsylvanian evaporites and caused uplift of a wedge-shaped, fault-bounded, pop-up block along the western edge of an evaporite sub-basin. Subsequent lateral thrusting related to continued uplift of the basement block caused faulting in the Mancos Shale and decollement and westward transport of the upper part of the Mancos Shale and rocks of the Mesaverde Group. According to Gunneson and others (1995), the Divide Creek Anticline was displaced two miles westward from where it originally formed.

GEOLOGIC HAZARDS

Mass wasting, flooding, hydrocompaction, and piping are the principal geologic hazards in the Gibson Gulch quadrangle. Mass-wasting processes are by far the most widespread hazard. The area of flood hazard is much smaller than that of potential mass wasting, but the risk is greater because there are more structures and people in or near areas that flood. Areas underlain by thick fine-grained sediment that was deposited by wind, sheet flow, mudflows, and debris flows during Holocene time may be susceptible to hydrocompaction, also referred to as collapsible soil. Areas of potential piping, the development of cylindrical and cavernous openings in dispersible soil and sediment, is minor compared to that in adjoining quadrangles, for example, the Hunter Mesa and Silt quadrangles (Madole, 1999; Shroba and Scott, 2001).

MASS WASTING

Mass wasting encompasses all forms of gravity-driven downslope movement of material regardless of rate, volume, or magnitude. The term mass movement commonly is used for individual modes of mass wasting and, in some contexts, as a synonym for mass wasting. Landslide classifications include most forms of mass movement, and, thus, the term landslide is applied to all but the slowest forms of mass movement regardless of whether movement was by fall, flow, or slide. In this discussion, debris flows and landslides are treated separately, except where they are components of complex mass movements as defined by Cruden and Varnes (1996).

Debris flows

Debris flows are dense mixtures of sand, silt, clay, rock debris, and lesser amounts of water and air that move as a fluid mass. Debris flows commonly resemble wet concrete that varies in degree of fluidity depending on the proportions of debris and water present. The amount of debris (material larger than 2 mm) in debris flows may range from as little as 20 percent to as much as 80 percent (Cruden and Varnes, 1996). Flows in which less than 20 percent of the material is debris are called mudflows in some mass-movement classifications (Selby, 1993).

Most debris flows in the Gibson Gulch quadrangle originate in the upper reaches of gullies and small valleys that drain sparsely vegetated slopes. Regardless of whether flow was initiated in valley heads or high on valley sides, most becomes channelized as it descends to the main valleys. Debris-flow deposits are major constituents of fan-shaped masses that accumulate where large gullies and tributary valleys join East Divide and West Divide Creeks. Debris-fan deposits (Qdf) and, in places, much of the colluvium in Qac consist of debris-flow deposits. The recurrence interval of debris flows on debris fans and in some areas of unit Qac depends primarily on the frequency of intense rain or heavy snowmelt and the time required to replenish the supply of debris swept away by the previous debris flow. The large amount of bare ground in some areas and the ease with which much of the Wasatch Formation and the residuum on it are eroded favors relatively rapid accumulation of loose material in some localities.

Landslides

A majority of the area in the Gibson Gulch quadrangle is vulnerable to slope failure for a several reasons. Weak rocks, high relief, steep slopes, and locally abundant moisture all contribute to landsliding in this area. Much of the Wasatch Formation consists of materials that are fine grained and weakly cemented. Oversteepened slopes caused by indurated resistant strata within and overlying the Wasatch Formation also contribute to landsliding. Furthermore, some strata of the Wasatch Formation may contain expansive clay minerals, which can reduce rock strength and slope stability.

The fact that landslide deposits mantle more than half of the Gibson Gulch quadrangle is indicative of the high potential for landsliding in the area. Many landslide deposits probably are relicts of the Pleistocene (in other words, they formed under different conditions of climate and vegetation than exist today) and are stable under present conditions. However, stable slopes, whether underlain by surficial deposits or bedrock, can be destabilized by human activities that replicate the wetter climate of the Pleistocene. Examples of such activities include irrigation, installation of septic systems, and diversion of surface runoff by roads, ditches, and other modifications of the land surface.

Landslides that occurred during the past century (see unit description for locations), afford clues as to where landsliding is apt to occur in the future. In addition, the nature and distribution of landslide deposits in general, regardless of age, provide insights into the probable causes of slope failure. Landslide deposits are particularly extensive on north-facing slopes and also are widespread in places on northwest-facing slopes because of a combination of mostly aspect-related factors. North- and northwest-facing slopes are in shadow for more hours each year than their south-facing counterparts and also are frozen for longer periods of time. They generally slope less steeply than south-facing slopes and are mantled by a thicker regolith, which retains more moisture and, thus, tends to support a denser cover of vegetation. These factors combine to reduce surface runoff and increase infiltration of precipitation. Saturation of regolith on steep slopes is a major cause of landsliding in this area. Landslides are less common on south-facing slopes in the semi-arid northern part of the quadrangle because the regolith generally is thin, vegetation is usually sparse, and evaporation and surface runoff are high.

The natural events that trigger landslides are well known. The principal natural triggering events worldwide are intense rainfall, rapid snowmelt, water-level changes, volcanic eruptions, and strong ground shaking during earthquakes (Wieczorek, 1996). In addition, human activities commonly trigger landslides. Unfortunately, humans continue to trigger landslides by neglecting simple fundamentals that have been well understood for decades (Brunsden, 1993). Erly and Kockelman (1981) discussed some of these these triggering activities, including (1) the use of earth fills for construction, (2) construction of buildings, roads, and other structures, (3) use of septic systems, and (4) landscaping activities, such as watering lawns, excavating, or cutting benches into hillsides. Most of the activities either add weight to the natural slope, which increases the shear stress in the area where the weight was added, or they remove support by excavating material, which reduces shear strength (the force that resists downslope movement of material). Excavations in footslope areas or at the toe of a slope are particularly troublesome. The weight of earth material commonly is overlooked when material is being rearranged by excavation and filling during construction. A layer of earth fill 1 ft thick is equivalent in weight to a single-story home of equal area (Erly and Kockelman, 1981). Also, activities that cause water—either from ground-water or surface-water sources—to be concentrated in localities that had not been heavily soaked before can cause slopes to fail. The added weight of the water increases shear stress and increased pore-water pressure reduces shear strength.

FLOODS

The area within the Gibson Gulch quadrangle that is subject to flooding is small compared to the area that is vulnerable to landsliding. However, flooding is more predictable and frequent than landsliding, and the risk is higher because most of the population in this quadrangle lives near flood-prone areas. Areas subject to debris-flows are also subject to flash floods. Thus, some parts of debris-fan deposits (Qdf) and unit Qac will flood occasionally. Areas of younger valley-floor alluvium (Qa_2) may flood one or more times per decade, which is more frequent than the flooding anticipated in areas of debris-fan deposits (Qdf) and unit Qac. Areas of older valley-floor alluvium (Qa_1) probably will flood in places, but only during large infrequent floods.

HYDROCOMPACTION

Areas underlain by thick deposits of fine-grained sediment that have low bulk density are susceptible to hydrocompaction. Low bulk density indicates that the sediment contains a relatively high volume of void space between grains. Such sediment may undergo a significant reduction in volume and collapse when wetted, or when weight, such as a building, is added, or when there is a combination of wetting and added weight.

Hydrocompaction is most common in relatively young (Holocene), fine-grained sediment deposited by wind, sheet flow, and some mudflows and debris flows because it contains entrapped air and a relatively high percentage of void space. Constituent grains may be only partly supported by adjacent grains and the weak bonding provided by clay and capillary attraction. Upon wetting, binding agents, such as clay, lose strength and shear, which results in a reorientation of mineral grains and a reduction of void space and a corresponding reduction in the volume of the material involved. Some fine-grained deposits may retain their potential to hydrocompact for a long time, especially in arid and semiarid climates where precipitation or ground water does not wet the deposits deeply and infiltrating meteoric water does not translocate appreciable quantities of colloidal clay downward into them.

In time, wetting and the force of gravity reduce the void space in fine-grained sediment, and materials such as clay, oxides of aluminum and iron, calcium carbonate and calcium sulfate fill voids and bond grains together. Thus, the potential for settling tends to decrease with time such that it is generally much less for Pleistocene deposits than for late Holocene deposits. In addition to age and bulk density, deposit thickness is important in determining the potential for soil collapse. Obviously, the thicker the deposit, the greater is the column of void space that can collapse.

In the Gibson Gulch quadrangle, most deposits of sheetwash alluvium and loess (units Qsw and Qlo) are Pleistocene and probably do not have a high potential for collapse, and, in addition, most loess is thin (< 6 ft). Deposits of Qsw and Qac that grade to present-day streams and deposits of Qaf that contain thick beds of alluvium and mudflow-deposits may be the most susceptible to hydrocompaction because they include sediment of Holocene age. Few data exist in the map area for evaluating this hazard. However, damage attributed to hydrocompaction has occurred in thick deposits of fine-grained sediment of Holocene age in urbanized areas in the Newcastle, Silt, and Rifle quadrangles (J. L. White, Colorado Geological Survey, written commun., 2001). Planning and design of engineered structures in localities underlain by thick deposits of sheetwash alluvium, loess, and debris-fan deposits should consider the potential for hydrocompaction.

PIPING

Piping refers to the development of vertical and horizontal openings along joints, cracks, and burrows in dispersible sediment or residuum that were enlarged by flowing water. Surficial materials containing clay that has a high percentage of exchangeable sodium, particularly sodium-montmorillonite, are susceptible to dispersion. In the area west of the Gibson Gulch quadrangle, piping primarily develops in thick deposits of older valley-floor alluvium (Qa_3) and sheetwash alluvium (Qsw) on valley floors where channel incision is deep. Where arroyos are incised to depths of 25–40 ft, as in the adjacent Hunter Mesa and Silt quadrangles (Madole, 1999: Shroba and Scott, 2001), vertical and horizontal cave-like pipes have developed to levels as deep as the arroyo floors. In places, the ground above horizontal pipes has collapsed and initiated the formation of deep holes and gullies, and where networks of subsurface pipes exist, collapsed ground is or may become extensive. In the Hunter Mesa quadrangle (Madole 1999), piping and collapsed ground have forced the relocation of a road and construction of a new bridge and have damaged land used for crops and grazing. Also, piping has caused significant problems in subdivisions in the Silt and Rifle quadrangles (J. L. White, Colorado geological Survey, written commun., 2001). Earthen dams and embankments constructed of dispersible surficial materials are susceptible to piping and collapse that can cause the structure to fail. Several arroyos in the northwestern part of the Gibson Gulch quadrangle and also near the southwest corner of the area are deeply incised. However, piping was not observed in these areas, although a few deep tributary gullies have formed there.

ECONOMIC GEOLOGY

The locations, names, and total depths (TD) of 28 wells are plotted on the Gibson Gulch map. This information is from COGIS, the Colorado Oil and Gas Conservation Commission GIS (Geographic Information Systems) database. All of the producing wells in the quadrangle are plotted and a few wells that formerly produced but are now shut-in also are plotted. Producing wells that are not in the COGIS database are not shown on the map. Wells in the Gibson Gulch quadrangle mainly produce gas, although some produce and sell small amounts of oil condensate. All wells are completed in the lower part of the Williams Fork Formation (Kmvl) of the Mesaverde Group. Completed zones include the Cameo-Wheeler-Fairfield coal zone of the Bowie Shale Member, and the Cozzette and Corcoran Sandstone Members of the Iles Formation. The most productive wells are in the northwestern part of the quadrangle. Recent exploration has centered on East Divide Creek.

The Rollins, Cozzette and Corcoran Sandstone Members of the Iles Formation continue to be exploration targets for gas wells in the Gibson Gulch quadrangle, but most gas production to date has come from the Cameo-Wheeler-Fairfield coal-bed zone. Coal beds of this zone also have been mined extensively where they are at or near the surface along the Grand Hogback Monocline. The Paonia Shale Member has been a minor source of coal along the Grand Hogback Monocline in an area southeast of the Gibson Gulch quadrangle.

Several surficial deposits in the Gibson Gulch quadrangle contain gravel, but much of it is matrix supported, and deposits of matrix-supported gravel rarely have commercial value. Even the clast-supported gravels in this area have limited commercial value at present, although some deposits could be exploited for local uses, such as constructing roadbeds. Most of the gravel deposits (1) underlie high terraces and mesas, many of which have limited access, (2) contain secondary calcium carbonate, much silty and clayey matrix, and abundant large cobbles and boulders; and (3) are mantled by windblown deposits. Extensive deposits of sand and gravel along the Colorado River are of better quality than those in the map area and are closer to population centers.

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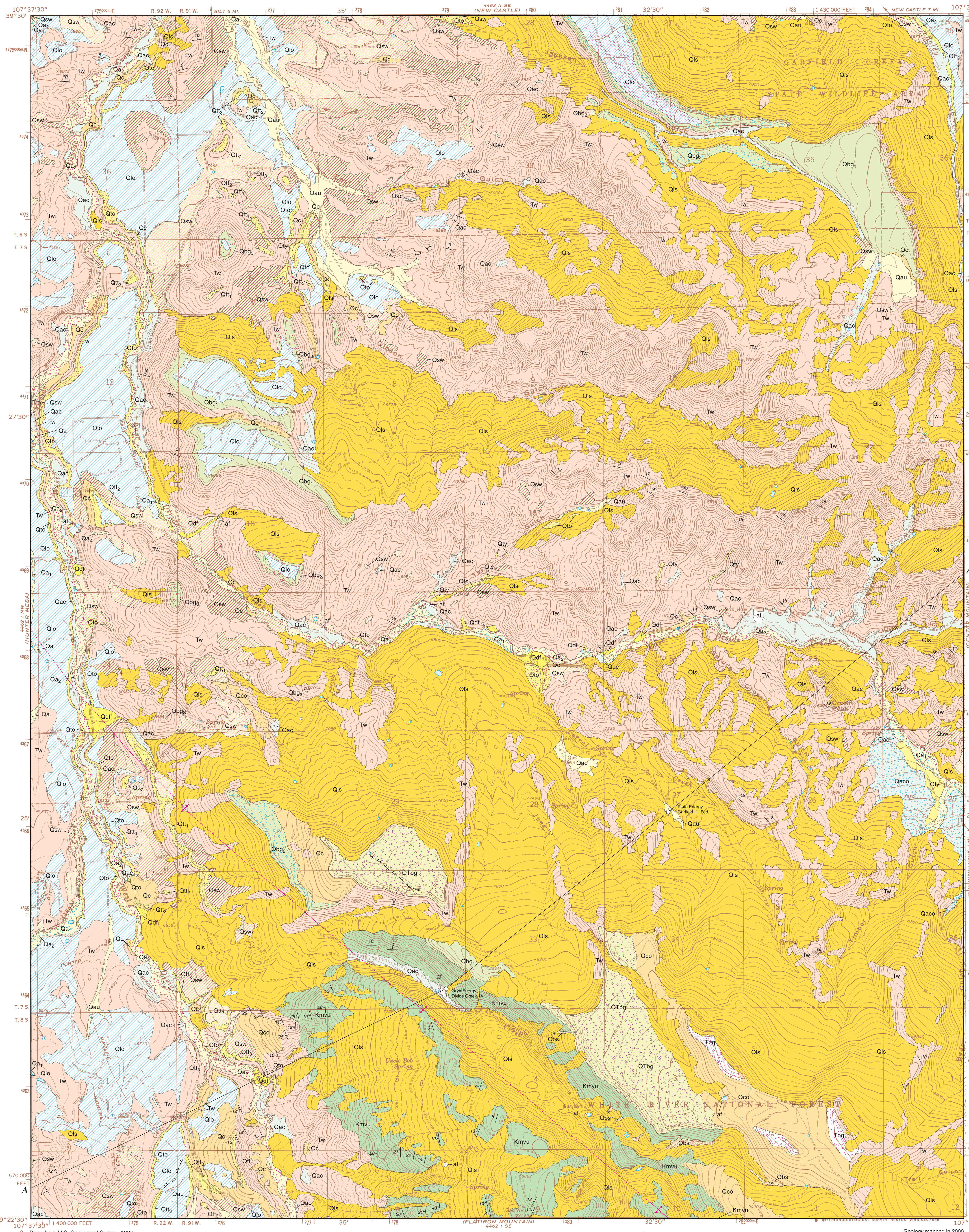
COLORADO GEOLOGICAL SURVEY
DIVISION OF MINERALS AND GEOLOGY
DEPARTMENT OF NATURAL RESOURCES
DENVER, COLORADO

OPEN FILE MAP 01-2
GEOLOGIC MAP OF THE GIBSON GULCH QUADRANGLE
GARFIELD COUNTY, COLORADO
Booklet accompanies map



Base from U.S. Geological Survey, 1983
10,000-foot grid based on Colorado coordinate system, central zone
1000-meter Universal Transverse Mercator grid ticks, zone 13

Geology mapped in 2000
Digital cartography by Cheryl Brchan and Jason Wilson

SCALE 1:24,000

CONTOUR INTERVAL 40 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

UTM GRID AND 1987 MAGNETIC NORTH
DECLINATION AT CENTER OF SHEET

QUADRANGLE LOCATION

CONDENSED DESCRIPTION OF MAP UNITS

The complete descriptions of map units and references are in the accompanying booklet.

SURFICIAL DEPOSITS

HUMAN-MADE DEPOSITS—Earth materials emplaced or modified by human activities

af — **Artificial fill (upper Holocene)**—Sand, silt, clay, and rock debris emplaced for road beds and embankments, earthen dams, and sites for drilling oil and gas wells

ALLUVIAL DEPOSITS—Sediment deposited by flowing water, either in stream channels or as unconfined sheet flow. Alluvium is the principal deposit underlying flood plains and stream terraces. As used here, a flood plain includes only the part of the valley floor that is flooded frequently. Sheetwash alluvium, the term for alluvium deposited by unconfined runoff, is mainly in sheets and wedges along footslopes of valley sides, on benches and terraces, and in hollows on hillsides

Qa_2 — **Younger valley-floor alluvium (upper Holocene)**—Chiefly very pale-brown to brown, poorly sorted sand, sandy silt, and minor gravel in channels and underlying flood plains and terrace remnants that are 1–3 ft higher than the flood plain. Alluvium borders most streams but is wide enough to show on the map only in the larger valleys

Qa_1 — **Older valley-floor alluvium (upper Holocene)**—Sediment is similar to that of the younger valley-floor alluvium (Qa_2). The older alluvium underlies terrace remnants 5–10 ft higher than streams. In deep, narrow valleys, the alluvium generally is poorly preserved, and Qac and Qc conceal much of what remains

Qau — **Alluvium, undivided (Holocene and upper Pleistocene)**—Chiefly very pale-brown to brown, poorly sorted sand, sandy silt, lenses and thin beds of gravel, and minor clayey sediment in upland valleys. The alluvium was not exhumed or incised deeply during the late Holocene, except locally in lowermost Gibson Gulch and East Gulch. Unit includes sediment that is correlative with units Qa_2 and Qa_1, and it includes alluvium of late Pleistocene age

Qsw — **Sheetwash alluvium (Holocene and upper Pleistocene)**—Chiefly very pale-brown, brown, and light-yellowish-brown poorly sorted to extremely poorly sorted sand, silty sand, sandy silt, clayey silt, and minor pebble- and cobble-size rock fragments. In places, sheetwash alluvium is eroded loess that was redeposited by sheet flow

Qty — **Younger terrace deposits (upper Pleistocene)**—Pale-brown to brown, very poorly sorted sand, silty sand, and beds and lenses of fine to coarse gravel underlying terrace remnants 20–40 ft higher than streams. Unit is mapped in only a few places, mainly along tributaries of East Divide Creek that drain south-facing slopes. Gravel is chiefly basaltic rock and sandstone fragments

Qto — **Older terrace deposits (middle Pleistocene)**—Chiefly extremely poorly sorted pebble, cobble, and boulder gravel underlying the most continuous and widespread terrace in the map area. The terrace is 100–140 ft higher than Divide Creek and 40–100 ft higher than East Divide Creek. In the West Divide Creek valley, it decreases upvalley from 140 ft to about 50 ft higher than the creek. Clasts are basaltic rock and sandstone. Loess blankets the gravel in most places

Qtt_3 — **Youngest high-terrace deposits (middle Pleistocene)**—Extremely poorly sorted pebble, cobble, and boulder gravel underlying terrace remnants in the southwestern part of the quadrangle and capping ridges and knolls in the northwestern part of the area. Gravel surface is about 160 ft higher than Divide Creek and, in the southern part of the map area, as low as 60 ft higher than West Divide Creek. Clasts are basaltic rock and sandstone

Qtt_2 — **Middle high-terrace deposits (middle Pleistocene)**—Sediment is similar to unit Qtt_3. Deposits cap ridges and knolls 200–260 ft higher than Divide Creek and, in the southern part of the map area, as low as 80–120 ft higher than West Divide Creek

Qtt_1 — **Oldest high-terrace deposits (middle Pleistocene)**—Sediment is similar to unit Qtt_3. Deposits underlie a terrace 280–400 ft higher than West Divide Creek in the southwestern part of the map area and about 200 ft higher than Gibson Gulch in the northwestern part of the area. Sheetwash alluvium and colluvium from adjacent slopes conceal much of the unit in most places

MASS-WASTING DEPOSITS—Earth materials that were transported downslope primarily by gravity, not by another medium such as wind, water, or ice

Qc — **Colluvium (Holocene and upper Pleistocene)**—Chiefly pale-brown to reddish-brown, very poorly sorted to extremely poorly sorted sand, silt, clay, and variable amounts of pebble- to boulder-size clasts. Most of the unit is on or just below slopes that range between about 15 and 35

Qco — **Older colluvium (middle and lower Pleistocene)**—Widely scattered large basaltic boulders, and variable amounts of pebbles, cobbles, and small boulders of basaltic rock and sandstone in a matrix of brown to reddish-brown, very poorly sorted to extremely poorly sorted sand, silt, and clay. These deposits may be remnants of old landslides or they may be products of frost heave and creep. Some deposits probably were derived from deposits of Tbg. Others are too high in the landscape to have been derived from existing uplands, and some are far from remnants of unit Tbg or other obvious sources of basaltic rock

Qls — **Landslide deposits (Holocene and upper Pleistocene)**—Nonsorted, heterogeneous mixture of surficial materials and fragmented rock debris in a wide range of particle sizes. Unit includes deposits of several ages; some are late Pleistocene in age and some were emplaced during the past few decades

Qbs — **Block-stream deposits (upper Pleistocene)**—Linear deposits of mostly large basaltic boulders on the valley floor and in gullies on the east valley wall of Clear Creek in the southeastern part of the map area. The deposits are devoid of matrix, at least in the upper 3–5 ft

ALLUVIAL AND COLLUVIAL DEPOSITS—Deposits of both alluvial and colluvial origin that are mapped as a single unit because they are interbedded or because they are juxtaposed and are too small to show individually or have contacts that are not clearly defined

Qac — **Alluvium and colluvium, undivided (Holocene and upper Pleistocene)**—Chiefly pale-brown to reddish-brown, extremely poorly sorted sand, silt, clay and pebble- to boulder-size rock fragments. Colluvium generally is less widespread than alluvium where slopes are less than 15

Qaco — **Older alluvium and colluvium, undivided (upper and middle Pleistocene)**—Sheets and lobes of extremely poorly sorted clast- and matrix-supported gravel deposited by streams and debris flows that coalesced along the footslopes of the upland south of East Divide Creek in the east-central part of the quadrangle. Gravel consists of angular to subrounded clasts of basaltic rock and sandstone, ranging in size from pebbles to boulders, in a matrix of sand, silt, and clay

Qdf — **Debris-fan deposits (Holocene)**—Extremely poorly sorted clast- and matrix-supported gravel and beds and lenses of fine-grained (< 2 mm) sediment in fan-shaped deposits at the mouths of steep, first- and second-order drainage basins. Clasts range from pebbles to small boulders, and they are mostly subangular to subrounded. The matrix is chiefly sand and clayey silt. These deposits are primarily products of flash floods, debris flows, and snowmelt runoff

Qbg_3 — **Youngest basaltic boulder gravel (middle or lower Pleistocene)**—Chiefly bedded, extremely poorly sorted pebble, cobble, and boulder gravel capping high, butte-like summits in the northwestern part of the quadrangle. Most deposits are 580 to 720 ft higher than East Divide and West Divide Creeks and about 400 ft higher than Gibson Gulch. Clasts are basaltic rock and sandstone

Qbg_2 — **Middle basaltic boulder gravel (lower Pleistocene)**—Deposits are similar to those of unit Qbg_3. Gravel underlies a terrace about 1,000 ft higher than West Divide Creek in the southwestern part of the quadrangle. It also caps a linear, gently sloping mesa (inverted paleochannel) about 1,000 ft higher than Garfield Creek (a major stream just north of the map area) in the northeastern part of the quadrangle

Qbg_1 — **Oldest basaltic boulder gravel (lower Pleistocene)**—Deposits are similar to those of unit Qbg_3. Gravel blankets mesas in the northeastern and west-central parts of the map area and it also caps a ridge in the south-central part of the map area, the crest of which is about 160 ft higher than the projected level of the upper surface of unit Qbg_2

QTbg — **Younger high boulder gravel (lower Pleistocene? or Pliocene)**—Deposits and landforms are similar to those of units of Qbg. Gravel caps mesas in the southern part of the quadrangle, about 360 ft higher than the projected level of unit Qbg_2. The upper surface of QTbg in sections 29 and 32 is at two levels that are separated by what appears to be a stream-terrace escarpment about 20 ft high

Tbg — **Older high boulder gravel (Pliocene or upper Miocene)**—Deposits and landforms are similar to those of units of Qbg. Gravel caps ridges in the southeastern part of the map area that are estimated to be about 900 ft higher than the projected level of unit Qbg_2 and that are nearly 3,000 ft higher than West Divide Creek, 3.7 miles to the west

EOLIAN DEPOSITS—Wind-deposited sediment consisting mostly of silt, very fine sand, and fine sand

Qlo — **Loess (upper and middle? Pleistocene)**—Reddish-brown, light-reddish-brown, and light-brown sandy silt and silty fine sand. Unit is thin (<3 ft) in areas that have overprint of pink dashes. In many places, contacts are only approximately located because the unit lacks topographic expression

BEDROCK

Tw — **Wasatch Formation (Eocene and Paleocene)**—Thick intervals of poorly to moderately indurated claystones and mudstones with subordinate interbedded and discontinuous beds of siltstone alternate with intervals of lenticular sandstone and conglomerate, all of non-marine origin. Fine-grained clastic rocks, ranging from very light gray to light brownish gray, reddish gray, olive gray, pale reddish brown and tan, make up more tha 75 percent of the formation. Sandstones are generally discontinuous, commonly lenticular, and yellowish gray, light gray and light olive gray in color. They also are commonly crossbedded and contain lenses of coarse sand and pebble conglomerate at channel bases

MESAVERDE GROUP (Upper Cretaceous)

Kmvu — **Upper part Williams Fork Formation**—Sandstone, siltstone, shale, and minor coal beds. Basal 500 ft of unit consists of shale and lenticular sandstone, siltstone, and coal beds of the Paonia Shale Member. Above the Paonia Shale Member are 3,200 ft of interbedded, mostly nonmarine sandstones, siltstone, shale, and thin lenticular coal beds. Locally, coarse-grained to conglomeratic sandstone fills channels cut in underlying strata. Only the uppermost part of the unit is exposed in the quadrangle along the crest and southwest flank of the Divide Creek anticline

Kmvl — **Lower part Williams Fork Formation, shown only in cross section**—Shale, sandstone, siltstone, coal, and minor algal limestone. Unit is the target for all oil and gas wells in the quadrangle. Unit contains the Bowie Shale Member, a 500 to 600 ft-thick section of shale and thin sandstone that has an important coal zone at the base. The 90 to 100 ft-thick Cameo-Wheeler-Fairfield coal zone is the predominant zone of gas production in this part of the Piceance Basin

MAP SYMBOLS

Contact—Dashed where approximately located

Terrace scarp—Separates contiguous deposits of same map unit; tick marks are on side of lower surface

Anticline—Axial trace; dashed where approximately located; dotted where concealed

Strike and dip of beds—Angle of dip shown in degrees

Wells drilled for oil and gas—

Well—Produces natural gas

Well—Dry hole; plugged and abandoned

Basaltic boulders—Isolated boulders on residuum or bedrock of the Wasatch Formation

A——*A′* **Alignment of cross section**

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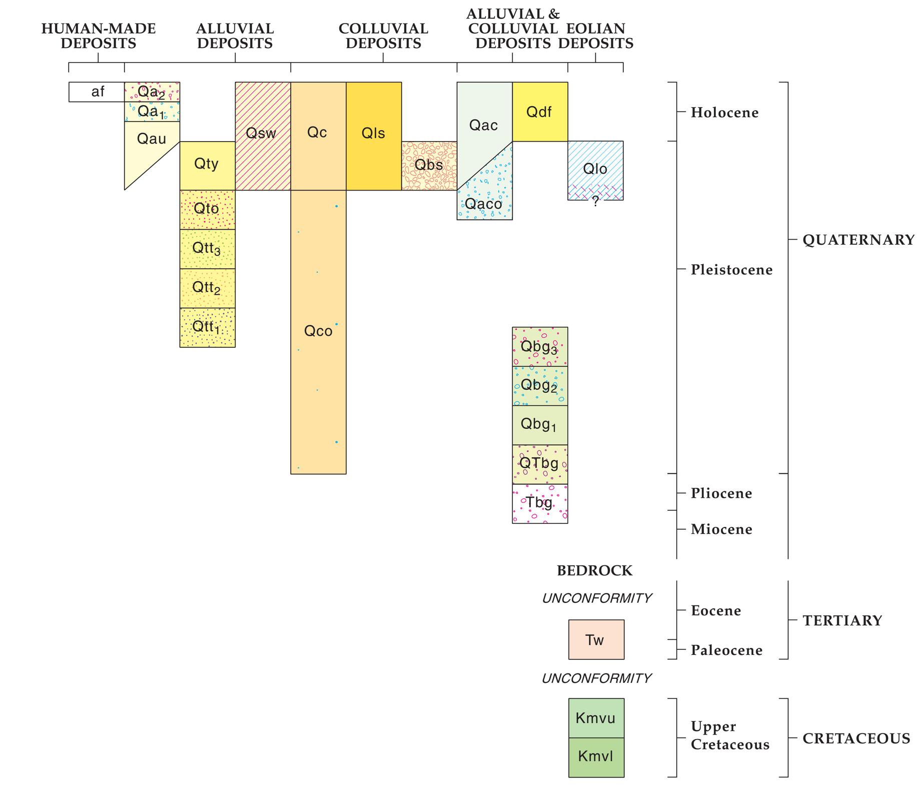
CORRELATION OF MAP UNITS



QUATERNARY TIME CHART

FORMAL TIME DIVISIONS		INFORMAL TIME TERMS	AGE (Sidereal years)
Quaternary Period	Holocene Epoch		
			~11,150
	Pleistocene Epoch	late Pleistocene	
			~128,000
		middle Pleistocene	
			~778,000
		early Pleistocene	
			~1,806,000
Tertiary Period (part)	Pliocene Epoch		

After Fullerton and others (in press)

GEOLOGIC TIME CHART

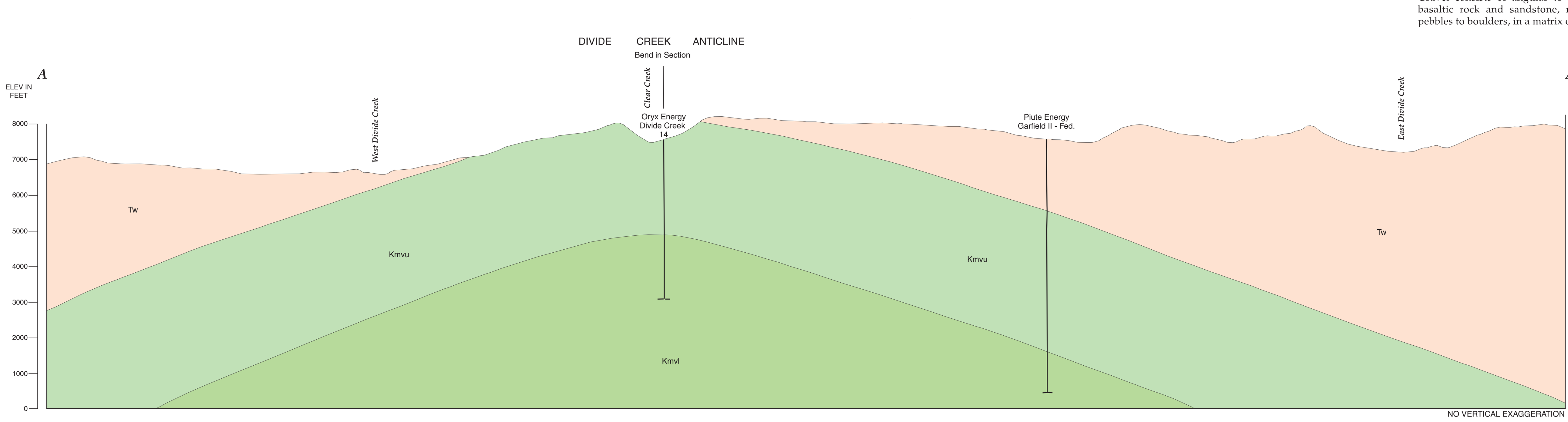
Terms and boundary ages used by the U.S. Geological Survey, 1986

EON	ERA	PERIOD		EPOCH	BOUNDARY AGE IN MILLION YEARS
Phanerozoic	Cenozoic	Quaternary		Holocene	
					0.01
				Pleistocene	
					1.8
		Tertiary	Neogene Subperiod	Pliocene	
					5
				Miocene	
					23
			Paleogene Subperiod	Oligocene	
					36
				Eocene	
					57
				Paleocene	
					66
	Mesozoic	Cretaceous		Late	
					96
				Early	
					138
		Jurassic		Late Middle Early	
					205
		Triassic		Late Middle Early	
					250
	Paleozoic	Permian		Late Early	
					290
		Pennsylvanian		Late Middle Early	
					~330
		Mississippian		Late Early	
					355
		Devonian		Late Middle Early	
					405
		Silurian		Late Middle Early	
					435
		Ordovician		Late Middle Early	
					510
		Cambrian		Late Middle Early	
					~570[1]
Proterozoic	Late Proterozoic				
					900
	Middle Proterozoic				
					1,600
	Early Proterozoic				
					2,500
Archean	Late Archean				
					3,000
	Middle Archean				
					3,400
	Early Archean				
		3800?			
pre-Archean[2]					4,550

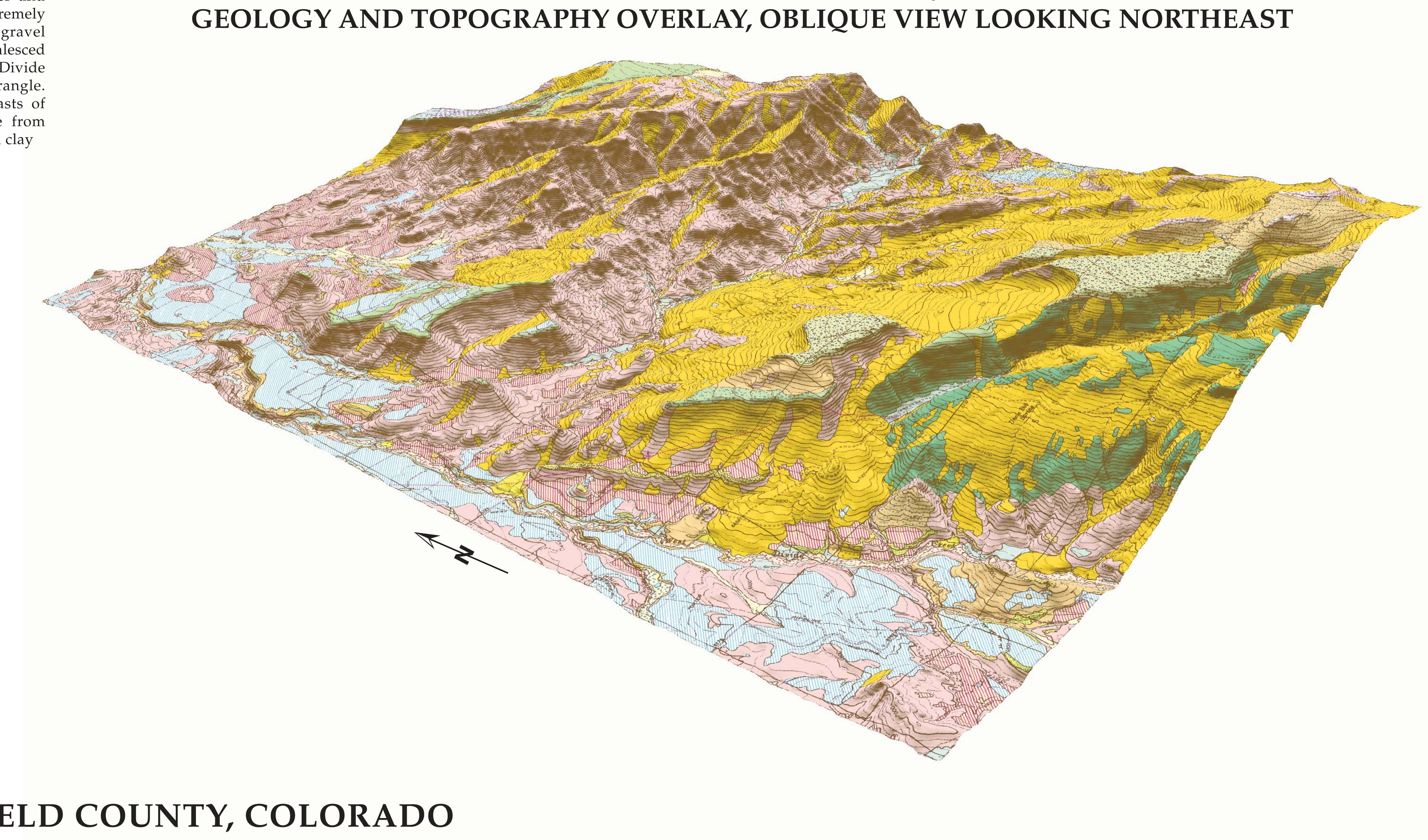
[1]Rocks older than 570 m.y. also called Precambrian, a time term without specific rank.
[2]Informal time term without specific rank.

OIL AND GAS WELLS IN THE GIBSON GULCH QUADRANGLE

1. Antara Resources
Gibson Gulch Unit/11-30
To depth = 5465 ft
2. Antara Resources
Gibson Gulch Unit No. 10-30
TD = 5,500 ft
3. Antara Resources
Gibson Gulch Unit No. 12-29
TD = 5,650 ft
4. Antara Resources
Gibson Gulch Unit No. 11-29
TD = 5,650 ft
5. Antara Resources
Gibson Gulch Unit No. 15-29
TD = 6,690 ft
6. Antara Resources
Gibson Gulch Unit No. 12-28
TD = 5,730 ft
7. Antara Resources
Duane Scott No. 1
TD = 6,460 ft
8. Antara Resources
Gibson Gulch Unit No. 13-30
TD = 5,400 ft
9. Antara Resources
Gibson Gulch Unit No. 14-30
TD = 5,380 ft
10. Antara Resources
Gibson Gulch Unit No. 15-30
TD = 5,265 ft
11. Antara Resources
Broome No. 1
TD = 6,600 ft
12. Antara Resources
Gibson Gulch Unit No. 13-29
TD = 5,476 ft
13. Antara Resources
Gibson Gulch Unit No. 13-28
TD = 6,830 ft
14. Antara Resources
Gibson Gulch Unit No. 4-31
TD = 5,370 ft
15. Antara Resources
Gibson Gulch Unit No. 3-31
TD = 5,412 ft
16. Antara Resources
Gibson Gulch Unit No. 2-31
TD = 5,500 ft
17. Antara Resources
Gibson Gulch Unit No. 8-31
TD = 5,350 ft
18. Antara Resources
Gibson Gulch Unit No. 11-32
TD = 6,525 ft
19. Antara Resources
Miller No. 1
TD = 6,550 ft
20. Amoco Production Co.
Hoffmeister-Rogers No. 15-20
TD = 6,000 ft
21. Timberline
Lillian B. Smith et al. No. 1
TD = 7368 ft
22. Maralex Resources
Rifle-Boulton No. 1
TD = 8,140 ft
23. Amoco Production Co.
Cameo No. 20-4
TD = 4,575 ft
24. Piute Energy
Garfield-Fed No. 6-27-7-91
TD = 7,111 ft
25. Maralex Resources
Federal No. 26-3
TD = 7,466 ft
26. Maralex Resources
Rifle-Walton No. 25-2
TD = 8,037 ft
27. Oryx Energy
Divide Creek No. 14
TD = 4,470 ft
28. Ballard
Divide Creek Unit No. 31
TD = 4,010 ft
29. Snyder Oil
Divide Creek Unit No. 12-wd
TD = 5,360 ft



SHADED-RELIEF MAP OF THE GIBSON GULCH QUADRANGLE WITH GEOLOGY AND TOPOGRAPHY OVERLAY, OBLIQUE VIEW LOOKING NORTHEAST



Bill Owens, Governor
State of Colorado

Greg Walcher, Executive Director,
Department of Natural Resources

Ronald W. Cattany, Director,
Division of Minerals and Geology

GEOLOGIC MAP OF THE GIBSON GULCH QUADRANGLE, GARFIELD COUNTY, COLORADO

By Richard F. Madole and Randall K. Streufert

2003