OPEN-FILE REPORT 00-04

Geologic Map of the Hesperus Quadrangle, La Plata and Montezuma Counties, Colorado

Geologic Setting, Description of Map Units, Geochemistry of Igneous Rocks, Mineral and Energy Resources, and References

By Robert M. Kirkham, David A. Gonzales, Christopher Poitras, Kendra Remley, and Douglas Allen

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Colorado Geological Survey
Division of Minerals and Geology
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This mapping project was funded jointly by the Colorado Geological Survey, U. S. Geological Survey, and Fort Lewis College through the National Cooperative Geologic Mapping Program under STATEMAP agreement No. 99HQAG0143 and EDMAP Agreement 99QAG0065.

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FOREWORD

The purpose of Colorado Geological Survey Open File Report 00-4, *Geological Map of the Hesperus Quadrangle, La Plata and Montezuma Counties, Colorado* is to describe the geological setting, geological hazards, and mineral resource potential of this 7.5 minute quadrangle located in the San Juan Basin of southwestern Colorado. Robert M. Kirkham of the Mineral Resources and Geological Mapping Section of the Colorado Geological Survey, and Dr. David A. Gonzales, a professor from Fort Lewis College in Durango, and three Fort Lewis College students; Christopher Poitras, Kendra Remly, and Douglas Allen, completed the field work on this project from July 1999 to October 1999. The objective of this publication is to provide geological maps in areas impacted by residential and other infrastructure development, especially those areas containing significant geological hazards and mineral and construction material resources to engineering companies, government planners, resource developers, and other interested citizens.

Funding for this project came from the Colorado General Fund. Matching funds were provided through a grant from the STATEMAP Component of the U.S. Geological Survey National Cooperative Geological Mapping Program. Dr. Gonzales and the three students from Fort Lewis College received a grant from the EDMAP Component of the U.S. Geological Survey National Cooperative Geological Mapping Program

James A. Cappa
Chief, Mineral Resources and Geological Mapping Section

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State Geologist and Director

INTRODUCTION

The Hesperus 7.5-minute quadrangle is located in La Plata County in southwestern Colorado, about 8 miles west of the town of Durango (figure 1). Geologic mapping of this quadrangle was conducted by the Colorado Geological Survey (CGS) and Fort Lewis College (FLC) as part of the STATEMAP and EDMAP components of the National Cooperative Geologic Mapping Program, which is administered by the U.S. Geological Survey (USGS). Geologic maps produced by the CGS through the STATEMAP program are intended as multi-purpose maps useful for land-use planning, geotechnical engineering, geologic-hazards assessment, and mineral-resource and ground-water exploration and development. An objective of the EDMAP component is to provide funding for geology students to conduct geologic mapping and scientific data analysis to expand the research and educational capacity of earth science academic programs. EDMAP projects must be coordinated with mapping programs at state geological surveys or with the USGS.

For this investigation Dr. D.A. Gonzales, FLC, and three students C. Poitras, K. Remley, and D. Allen, were responsible for most of the mapping in the northern one-third of the quadrangle, work funded in part by the EDMAP component. R.M. Kirkham, CGS, mapped the bedrock in the southern two-thirds of the quadrangle and most of the surficial geology in the entire map area. This work was supported by the STATEMAP component. Our map is based upon exposures, float, and landforms observable at the earth's surface; we did not conduct any underground mapping or underground reconnaissance surveys.

Several prior geologic maps greatly aided our mapping effort. Cross and others (1899) conducted the first in-depth investigation of the La Plata region. Eckel (1949) described the geology, mineralization, and mining history of the entire La Plata Mountains. He published a 1:31,680-scale map of that area, which included the northern one-third of the Hesperus quadrangle. His descriptions of individual underground mine workings are especially valuable, as most portals have collapsed shut and are not easily accessible. In many areas outcrops are very limited; relationships exposed in the mine workings were interpreted by Eckel (1949) and incorporated into his map. In part because our mapping is based exclusively on surface exposures, it differs from Eckel's map. The southern part of the quadrangle was mapped at a scale of 1:31,680 by Zapp (1949), who focused on coal geology. The Hesperus

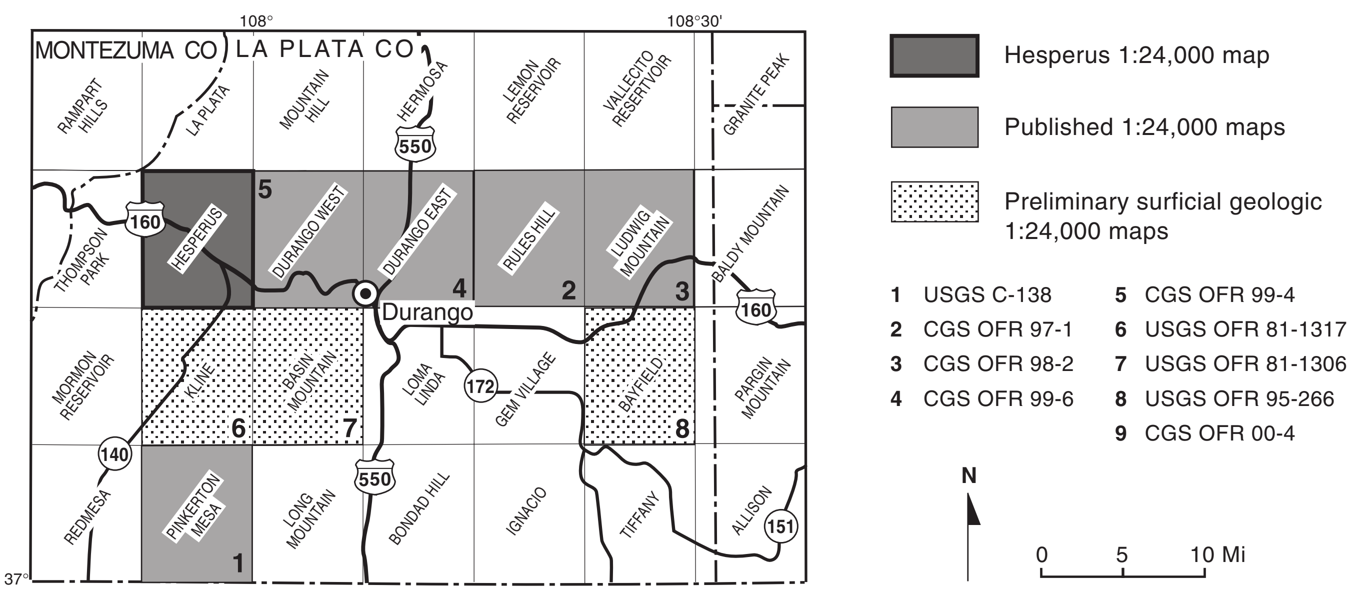

Figure 1. Status of 1:24,000-scale geologic mapping of 7.5-minute quadrangles near Durango, Colorado.

quadrangle was included in the 1:250,000-scale geologic map by Haynes and others (1972). Condon (1990) mapped the geology of the southern part of the quadrangle at a scale of 1:100,000.

Figure 1 depicts the current staus of geologic mapping of 7.5-minute quadrangles in the Durango area. The Rules Hill, Ludwig Mountain, Durango East, and Durango West quadrangles were mapped and published by the CGS during previous STATEMAP projects in 1997, 1998, and 1999 (Carroll and others, 1997, 1998, 1999; Kirkham and others, 1999) The Hesperus quadrangle was mapped during fiscal year 1999-2000.

A few landowners denied us access to conduct field work on parts of the quadrangle (figure 2). In these areas our mapping was largely based upon prior published geologic studies, interpretation of aerial photography and drill hole logs, and visual inspection from a distance using binoculars. The mapping in these areas should be considered reconnaissance or preliminary.

GEOLOGIC SETTING

The Hesperus quadrangle straddles a major regional structural boundary that separates the Four Corners platform from the San Juan dome in southwestern Colorado (figure 3). The quadrangle is in the eastern part of the Four Corners platform, a broad, northeast-trending structural bench that extends from northwestern New Mexico into southwestern Colorado and is underlain by relatively flat-lying sedimentary rocks (Haynes and others, 1972; Woodward and others, 1997). The platform structurally separates several surrounding uplifts and basins in southwestern Colorado and northwestern New Mexico. Within the southwestern part of Hesperus quadrangle, rocks in the platform generally dip about 5 degrees southwest, south, or southeast.

The San Juan dome is a roughly circular, broad, domal uplift that forms the northeastern side of the Four Corners platform (figure 3). The Laramide-age (early Tertiary-Upper Cretaceous) San Juan dome extends across much of the mountainous part of southwestern Colorado and is in large part concealed by the middle Tertiary San Juan volcanic field. A smaller, more abrupt dome, the laccolithic La Plata dome, is superimposed upon the southwestern end of the larger San Juan dome (figure 3).

The La Plata domal uplift resulted from intrusion of 75 to 60 Ma plutonic rocks (Cunningham and others, 1994; unpublished $^{40}Ar/^{39}Ar$ age determinations performed in 1996 by W. McIntosh, New Mexico Bureau of Mines and Mineral Resources for D. A. Gonzales). As a result of this period of intrusion, the late Paleozoic and Mesozoic sedimentary section has been inflated 6,000 to 8,000 ft (Eckel, 1949; Haynes and others, 1972). The plutonic rocks consist largely of sill-shaped stocks and sheets emplaced at various stratigraphic horizons and numerous sills and dikes that cut surrounding country rock. These plutonic rocks are dominantly dioritic to syenitic in composition, and include late-phase lamprophyre dikes. The mountainous northern end of the Hesperus quadrangle is carved out of the southern part of the La Plata dome. Along the southern margin of this dome the sedimentary country rocks are generally only slightly metamorphosed to unmetamorphosed.

The southeastern flank of the Four Corners platform is bordered by the northwestern margin of the San Juan Basin, another large, Laramide structure (figure 3). This major structural boundary coincides with the Hogback monocline, a sharply southeastward dipping structure that lies only three to six miles beyond the southeastern corner of the Hesperus quadrangle. In the southwestern part of the Hesperus quadrangle, rocks in the Four Corners platform generally dip about five degrees southwest, south, or southeast. Although some minor faults and folds may be present in this area, none were mapped at the surface during this investigation. A few minor rolls or folds have been encountered in the underground workings of the King Coal mine, but no faults have been intersected (Trent Peterson, 1999, oral communication).

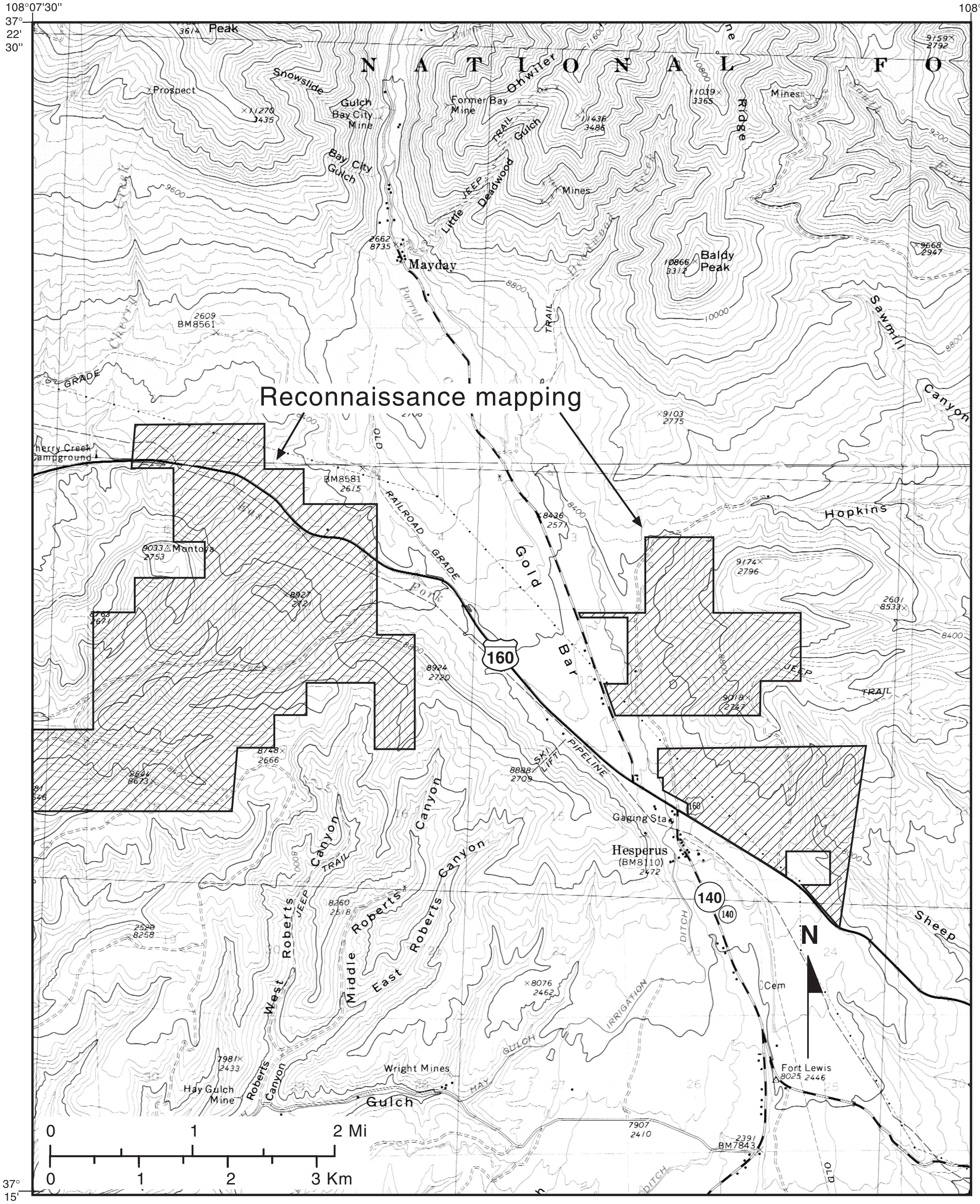

Figure 2. Approximate extent of areas (hachured) where only reconnaissance mapping was conducted due to restricted access.

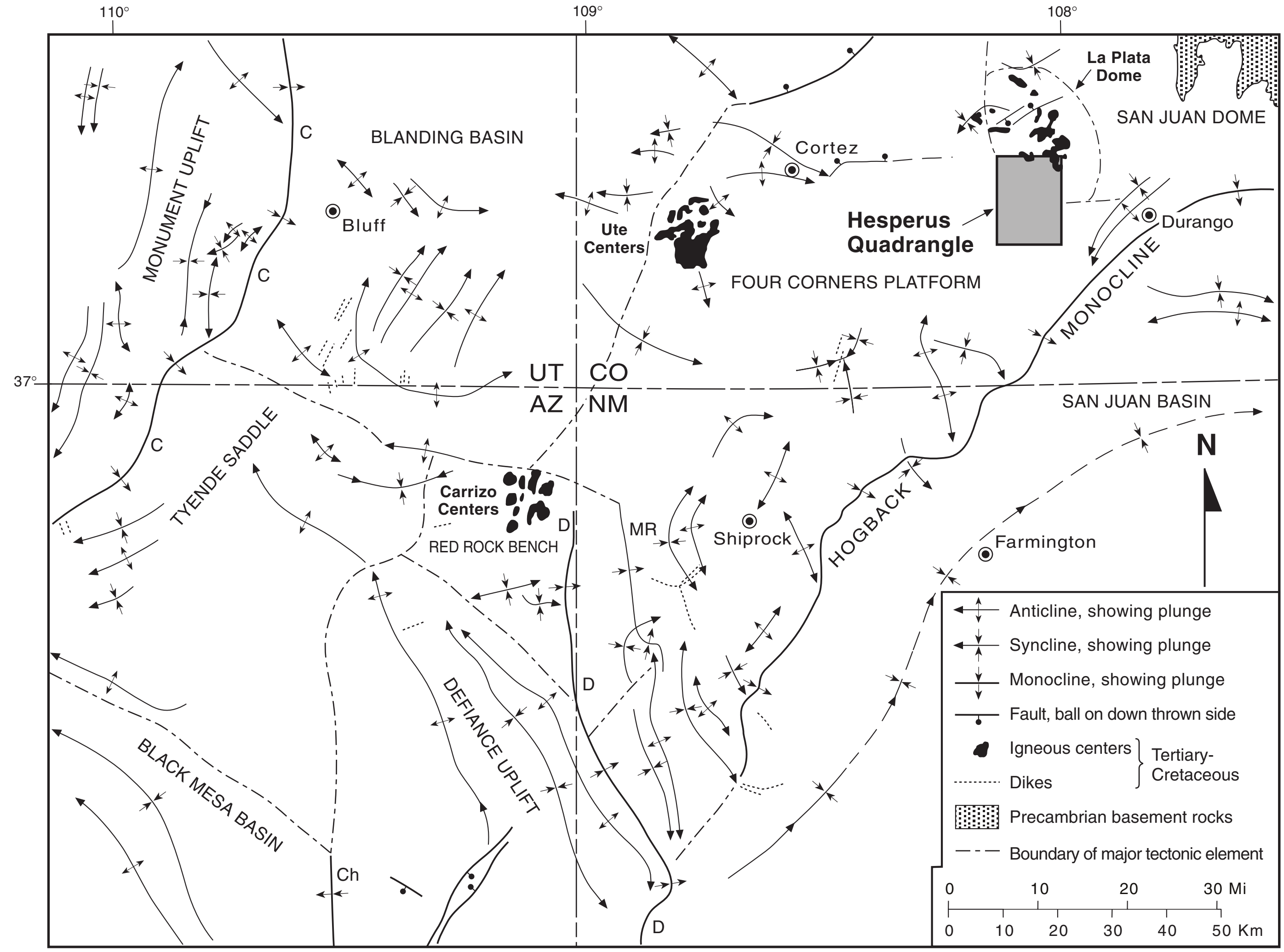

Figure 3. Generalized tectonic map of the Four Corners area. Modified from Woodward and others (1997). C = Comb monocline, Ch = Chinle monocline, D = Defiance monocline, and MR = Mitten Rock monocline.

Between the Four Corners platform and La Plata dome the beds gradually steepen, a result of magmatic inflation and uplift associated with the La Plata dome. Within and adjacent to the dome, the sedimentary rocks can be highly deformed by faults and folds. In the Hesperus quadrangle the rocks were locally deformed during emplacement of intrusive rocks, but not consumed or incorporated into the magmas to any significant degree. Abruptly thickening sills and the sharp edges of stocks sometimes dramatically deform or offset sedimentary strata.

Several high-angle, down-to-the-south, faults along the margin of the La Plata dome were recognized by Eckel (1949) and during this investigation. These faults trend approximately east-west. The largest fault in the quadrangle, the Ohwiler Ridge fault, has at least 400 to 450 ft of stratigraphic throw where the Morrison Formation is faulted against undifferentiated Dolores/Cutler rocks. A series of subparallel, anastomosing faults, called the Mayday-Idaho fault system by Eckel (1949), border the dome near Mayday. They probably formed in response to flexure due to the structural doming or inflation related to emplacement of the intrusive rocks. The Idaho fault, the northernmost splay, offsets the rocks about 50 to 100 ft, whereas 300 to 375 ft of displacement occurs on the Mayday fault, the southern splay (Eckel, 1949). Nearly all slickensides exposed in underground workings inspected by Eckel suggested the last movement on the faults was largely horizontal.

Hydrothermal, telluride-rich, precious-metal and base-metal mineralization accompanied or followed Laramide igneous activity. Veins and replacement deposits of gold- and silver-bearing telluride ores are the primary historical mining targets in the La Plata mining district (Eckel, 1949). Base-metal copper deposits also produced significant ore.

ACKNOWLEDGMENTS

This geologic mapping project was funded jointly by the Colorado Geological Survey, U.S. Geological Survey, and Fort Lewis College through the National Cooperative Geologic Mapping Program of 1997 under STATEMAP Agreement 99HQAG0143 and EDMAP Agreement no. 99AQAG0065. Rob Fillmore, Western State College, and Chris Carroll and Jim Cappa, Colorado Geological Survey, reviewed this map and booklet. Their comments and suggestions greatly improved this publication, however, the authors are solely responsible for any errors in the published report.

We appreciate the stimulating discussions and/or field reviews with Steve Korte, Trent Peterson, Mary Gillam, Don Owen, Rob Blair, Bob Raynolds, Robyn Wright-Dunbar, and Robert Zech. Special thanks to John and Bonnie Brennan and LaVern Gwaltney, Stewart Ranch, for granting permission for extended use of their ranch roads to access the remote northeastern part of the quadrangle. Mike Johnson and Dick Bell, U.S. Forest Service, kindly assisted our efforts to acquire a special use permit to drive all-terrain vehicles on old roads on Forest Service lands. We also thank Pee Wee Botkin for loaning us his all-terrain vehicle, which greatly accelerated our mapping in the remote northeastern part of the quadrangle. The Ute Mountain Ute Tribal Council granted permission to work on tribal lands in the southwestern part of the quadrangle. Bill Lupien graciously allowed us to utilize the roads on Shalako Ranch to access the remote parts of Deadwood Creek on several occasions. We also appreciate the many other helpful landowners who gave permission to enter their property and contributed valuable information.

Alan Andrews, La Plata County, created very helpful land ownership maps for us. National King Coal, LLC, provided geophysical and lithologic logs for several coal exploration drill and core holes and shared their knowledge of Mesaverde Group stratigraphy, a cooperative effort facilitated by Trent Peterson and Steve Korte.

Photogrammetric models were set by James Messerich on a Kern PG-2 plotter at the USGS laboratory in Denver. Bill McIntosh, New Mexico Bureau of Mines and Mineral Resources, conducted the $^{40}Ar/^{39}Ar$ dating. Jane Ciener served as the technical editor for this map.

DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSITS

Surficial deposits shown on the map are generally more than 5 ft thick but are locally thinner. Artificial fill of limited areal extent and residuum were not mapped. Contacts between surficial units may be gradational, and mapped units locally may include deposits of another type. The modified Wentworth grain-size scale is used to describe the surficial deposits. Some of the surficial deposits are calcareous and contain varying amounts of both primary and secondary calcium carbonate. Divisions of the Pleistocene used herein correspond to those of Richmond and Fullerton (1986). Relative age assignments for surficial deposits are based primarily on the degree of erosional modification of original surface morphology, height above modern stream levels, and relative degree of weathering and soil development.

HUMAN-MADE DEPOSITS—

af **Artificial fill (latest Holocene)—**Consists of fill and waste rock placed during construction of roads and dams. Unit is composed mostly of unsorted silt, sand, and rock fragments but may include construction materials. Maximum thickness is about 30 ft. Artificial fill may be subject to settlement when loaded, if not adequately compacted.

cmw **Coal mine waste (latest Holocene)—**ncludes rock debris and coal refuse in dump piles and in operational areas near coal mines. Maximum thickness is about 40 ft. Coal mine rm **Reclaimed mine waste (latest Holocene)—** Consists of rock fragments and surficial deposits that have been reclaimed at several coal mine sites. This reclamation work was been performed as part of permitted mine requirements or by the Abandoned Mine Land program of the Colorado Division of Minerals and Geology. Reclaimed materials may be prone to settlement or erosion.

ALLUVIAL DEPOSITS—Silt, sand, and gravel deposited in stream channels, flood plains, glacial outwash terraces, and sheetwash areas along the La Plata River and its tributaries. Terrace alluvium along the La Plata River is chiefly glacial outwash that was probably deposited during late-glacial and early-interglacial stages. Alluvial deposits locally include sheetwash, colluvium, or loess too small to be mapped at a scale of 1:24,000. The approximate terrace heights reported for each unit are the elevation differences measured between the adjacent modern stream valley and either the top of the original alluvial deposition surface near the forward edge of the terrace or the top of the preserved deposit, if eroded. The terraces above the La Plata River converge with the modern stream channel, so the corresponding heights of the terraces above the river diminish in a downstream direction across the quadrangle.

Qa **Stream channel, flood-plain, and low terrace deposits (Holocene)—**Includes modern stream-channel deposits of the La Plata River, adjacent flood-plain deposits, and low-terrace alluvium that is up to 8 ft above modern stream level. Unit may include deposits of terrace alluvium one (Qt_1) downstream of Hesperus where modern stream gradients and terrace heights are significantly reduced. These deposits are mostly poorly sorted and clast supported. They consist of unconsolidated pebble, cobble, and locally boulder gravel in a sandy or silty matrix. Locally the unit is interbedded with or overlain by sandy silt and silty sand. Clasts are well rounded to subangular. Deposits contain clasts composed mostly of diorite porphyry, various colored sandstone, and monzonite porphyry, with lesser amounts of siltstone, conglomerate, limestone, syenite porphyry, and lamprophyre; the clasts reflect the wide variety of intrusive and sedimentary rocks that crop out in the La Plata River drainage basin. Maximum thickness is estimated at 20 ft. Low-lying areas are subject to flooding. Unit may contain placer gold (Eckel, 1949) and is a source of sand and gravel.

Qsw **Sheetwash deposits (Holocene and late Pleistocene)—**Includes materials that are transported chiefly by sheetwash processes and deposited in valleys of ephemeral and intermittent streams, on gentle hillslopes, or in topographic depressions. These deposits are locally derived from weathered bedrock and surficial materials. Sheetwash deposits typically consist of pebbly, silty sand, sandy or clayey silt, and sandy, silty clay. Locally they grade to and interfinger with colluvium (Qc) on steeper hillslopes and with lacustrine or slack-water deposits in closed depressions. The maximum thickness is about 25 ft, but commonly the deposits are much thinner. Area is subject to future sheetwash deposition. Unit may be prone to hydrocompaction, settlement, and piping where fine-grained and low in density.

Qt_1 **Terrace alluvium one (late Pleistocene)—** Chiefly stream alluvium that underlies several terrace surfaces along or near the La Plata River. These terraces sharply converge with the river in a downstream direction. Unit includes a paired set of terrace remnants on either side of the lower end of Deadwood Creek that was locally derived from that drainage. Along the La Plata River at the southern edge of the La Plata Mountains, terraces associated with terrace alluvium one are as much as 100 ft above the river, whereas near the southern edge of the quadrangle they are only 10 to 35 ft above it. The unit is mostly poorly sorted, clast-supported, locally bouldery, pebble and cobble gravel in a silty or sandy matrix. It may include fine-grained overbank deposits or overlying sheetwash deposits. Clasts are mainly subround to round, and they are composed of the varied bedrock lithologies that crop out within the La Plata River drainage basin, mostly diorite porphyry, sandstone of various colors, and monzonite porphyry, with lesser amounts of siltstone, conglomerate, limestone, syenite porphyry, and lamprophyre. Clasts are generally unweathered or only slightly weathered.

Terraces related to terrace alluvium one grade to Qm_1 moraines about 0.6 mi south of the town of Mayday. These terraces are tentatively correlated with terrace group TG7 of Gillam (1998) in the Animas River valley, which is graded to the Animas City moraines in the Durango East quadrangle (Carroll and others, 1999). These moraines, which formed roughly from 12 to 35 ka (Richmond, 1986; Carroll and others, 1999), are probably equivalent to Pinedale and other late-Wisconsin moraines elsewhere in the Rocky Mountains. Terrace alluvium one also in part correlates with Pinedale outwash (Qpo) and upper Holocene alluvium (Qal) of Scott and Moore (1981). Exposures in and north of the town of Hesperus suggest terrace alluvium one deposits are thin, ranging from about 5 to 10 ft thick. Driller's logs from water wells near the southern edge of the quadrangle report thicknesses as much as 36 ft (unpublished water well records held by the Colorado Division of Water Resources). In addition to the apparent downstream thickening, buried channels may contain thicker deposits of terrace alluvium one. This unit is a source of sand and gravel and has been previously mined at several locations. During the summer of 1999 it was actively mined for use during the reconstruction work of U.S. Highway 160. It may contain placer gold (Eckel, 1949).

Qt_2 **Terrace alluvium two (late? and late middle Pleistocene)—**Chiefly stream alluvium that underlies at least two terrace surfaces along the La Plata River. These terraces dramatically converge with the river in a downstream direction but are higher above the river than the terraces included in terrace alluvium one (Qt_1). Near the southern edge of the quadrangle these terraces are about 80 ft above the river. At the upper end of Gold Bar, about 1.3 mi south of Mayday, a Qt_2 terrace grades to a Qm_2 moraine. At this location the Qt_2 terrace is 150 to 160 ft above the river. Deposits of terrace alluvium two are texturally and lithologically similar to terrace alluvium one deposits (Qt_1). Clasts within terrace alluvium two deposits are slightly weathered, and soils formed on the surface of the unit commonly have a moderately well developed textural B horizon. The unit locally includes overlying sheetwash deposits, colluvium, and loess that may be several feet thick.

Terrace alluvium two deposits correlate with Bull Lake? outwash (Qbo) in the Kline quadrangle (Scott and Moore; 1981). Terraces associated with this unit are probably equivalent in age to terrace group TG6 of Gillam (1998), which is graded to Spring Creek moraines in the Animas River valley in the Durango East quadrangle (Carroll and others, 1999). These moraines are correlated with Bull Lake, Eowisconsin, and other moraines of similar age elsewhere in the Rocky Mountains (Richmond,1986; Gillam, 1998). Gillam (1998) suggested an age range of 85 to 160 ka for Spring Creek moraines and terrace group TG6 along the Animas River, and the terraces related to terrace alluvium two in the Hesperus quadrangle are probably of similar age. This age range was based upon poorly constrained amino-acid-racemization dates for snails in alluvium overlain by Spring Creek moraines (Gillam, 1998) and on dates for deposits in other areas (as summarized by Richmond, 1986; see also Sturchio and others, 1994; and Chadwick and others, 1994).

Although this unit is widely preserved along the river valley, exposures of the entire thickness of terrace alluvium two are rare. In the NW1/4 of section 3, T. 35 N., R. 11 W. the deposit appears to be 10 to 20 ft thick in a badly sloughed road cut. The unit was 30 to 35 ft thick in an excavation for a natural gas pipeline near the southern tip of Gold Bar. Driller's logs from water wells near the southern margin of the quadrangle suggest the presence of a buried alluvial channel in terrace alluvium two in the SW1/4 of section 26 and SE1/4 of section 27, T. 35 N., R. 11 W. (unpublished water well records held by the Colorado Division of Water Resources). Gravel thickness in that area ranges from 20 to 72 ft in wells that penetrated through the alluvium, and one 80-ft-deep well never reached bedrock. To the south on Kline quadrangle Scott and Moore (1981) report a thickness of 200 ft based on a driller's log from a water well. Terrace alluvium two is a source of sand and gravel and has been worked at several locations in the quadrangle. It may contain placer gold.

Qt_3 **Terrace alluvium three (middle Pleistocene)–** Chiefly stream alluvium that underlies at least three terrace surfaces along the La Plata River that are higher than terraces included in terrace alluvium two (Qt_2). Terraces associated with terrace alluvium three sharply converge with the river in a downstream direction. Near the southern edge of the quadrangle Qt_3 terraces range from about 110 to 130 ft above the river.

West of the northern end of Gold Bar a small remnant of a Qt_3 terrace grades to older moraine deposits (Qt_3). This northernmost remnant of a Qt_3 terrace is about 320 to 350 ft above the river, suggesting Qt_3 terraces lose over 200 ft in height above the river in a horizontal distance of only about 6 mi .

Terrace alluvium three deposits generally have textural and lithological characteristics that are similar to those of terrace alluvium one (Qt_1). An exception to this general rule was noted in the SE 1/4 of section 26, T. 35 N., R. 11 W., where the clast lithology is chiefly sandstone and siltstone locally derived from the Cliff House Sandstone and perhaps Menefee Formation, and the gravel matrix contains more silt than in other areas. This deposit was probably related to a tributary paleochannel that drained bedrock hills on the west side of the river valley. Clasts within terrace alluvium three are moderately weathered. The unit locally includes overlying sheetwash deposits, colluvium, and loess up to several feet thick.

Terrace alluvium three is correlative to Kansan? outwash (Qko) on Kline quadrangle (Scott and Moore, (1981). The highest terrace included in terrace alluvium three is subparallel to and about one-half mile west of Sheep Springs Gulch in the southeast part of the quadrangle. This uppermost Qt_3 terrace correlates with the Kansan? outwash terrace in the Kline quadrangle; that terrace is overlain by the 600 ka Lava Creek B ash and lies 105 to 115 ft above the La Plata River (Scott and Moore, 1981). The lower Qt_3 terraces in the Hesperus quadrangle may correlate with the topographically lower Kansan? outwash terraces mapped by Scott and Moore (1981) or to terrace group TG5 of Gillam (1998). Gillam's terrace group TG5 grades or projects to the inner (younger) Durango moraines in the Durango West and Durango East quadrangles (Kirkham and others, 1999; Carroll and others, 1999). Gillam (1998) suggested that the inner Durango moraines formed during the coldest part of oxygen-isotope stage 8 at about 250 to 275 ka.

Thickness of terrace alluvium three deposits in the Hesperus quadrangle is poorly constrained. The unit is 22 ft thick in a fresh road cut along Highway 160 about 1.4 miles southeast of the junction with Highway 140. Where county road 125 (old Highway 160) descends from the Qt_3 terrace in the southeast corner of the quadrangle, the deposit is about 30 ft thick. To the south in the Kline quadrangle Scott and Moore (1981) reported thicknesses as much as 145 ft based on driller's log from water wells. This suggests buried channels filled with Qt_3 alluvium may exist in the Hesperus quadrangle. Terrace alluvium three is a source of sand and gravel. One pit along Highway 160 was active during the summer of 1999. The unit may contain placer gold.

COLLUVIAL DEPOSITS—Silt, sand, gravel, and clay on valley sides, valley floors, and hillslopes that were mobilized, transported, and deposited primarily by gravity.

Qlsr

Recent landslide deposits (latest Holocene)— Includes several recently active landslides with fresh morphological features that suggest movement during the past several decades. The largest recently active landslide is in the northwest part of the quadrangle west of Parrott Creek and north of Highway 160. It apparently involves partial reactivation of an older landslide that originated in the Mancos Shale. An abandoned railroad grade has been displaced as much as about 300 ft by the recent landslide. Another recent landslide involving reactivated older landslide deposits occurs immediately west of the large recent landslide just described. Three small recent landslides associated with the Dakota Sandstone and Burro Canyon Formation are near the eastern margin of the quadrangle in Sawmill Canyon. One or more of these may be related to failure or overtopping of the bank of the Big Stick ditch. A small area of Mancos Shale and a thin overlying veneer of colluvium derived from terrace deposits that caps the hill above the slide were involved in a recent landslide on the east side of the La Plata River between Hopkins Gulch and Deadwood Creek. A small landslide east of Mayday occurred in the Morrison Formation and a thin, overlying mantle of colluvium and residuum. Another recently reactivated landslide developed in the upper end of West Roberts Canyon. This landslide was originally formed in the Menefee Formation, which is exposed in the headscarp of the recent slide. Several small recent slumps or earthflows have involved the Menefee Formation and overlying residuum and colluvium in upper Sheep Springs Gulch and in unnamed tributaries to upper Hay Gulch north of the Wright no. 1 and 2 mines. The recent landslide along county road 125 (old Highway 160) in the southeast corner of the quadrangle initiated in the Lewis Shale along the margin of the mesa capped by terrace alluvium three. This slide, which formed in the headscarp of an older landslide, has affected the county road.

Recent landslide deposits are heterogeneous and consist of unsorted, unstratified rock debris, clay, silt, sand, and sometimes rounded river gravel. Texture and clast lithology depend upon provenance area. Maximum thickness may exceed 30 ft. These deposits are prone to renewed or continued landsliding and may be susceptible to settlement when loaded. They also indicate the setting in which future slope failures will likely occur. Soil slips (see explanation of map symbols) are thin, areally small, recent landslides that formed on steep slopes mantled by colluvium or residuum. However, they are too small to be shown as a map unit at a scale of 1:24,000. Shallow groundwater may be present within areas mapped as recent landslide deposits.

Qt **Talus (Holocene and late Pleistocene)—** Angular, cobbly, and bouldery rubble on moderate to steep slopes below cliffs of diorite porphyry, monzonite porphyry, Dakota Sandstone/Burro Canyon Formation, Morrison Formation, Entrada Sandstone, and Junction Creek Sandstone. Unit commonly lacks matrix and locally is underlain by or incorporated into landslides. Talus on Parrott Peak includes deposits of felsenmeer. Maximum thickness is estimated at 50 ft. Mapped areas are subject to severe rockfall, rockslide, and rock-topple hazards. Talus may be a source of riprap.

Qc **Colluvium (Holocene and late Pleistocene)—**Ranges from unsorted, clast-supported, pebble to boulder gravel in a sandy or silty matrix to matrix-supported gravelly sand or clayey silt. Colluvium is derived from weathered bedrock and surficial deposits and is transported downslope primarily by gravity, sometimes aided by sheetwash. Locally it grades to sheetwash deposits on flatter slopes and to debris-flow deposits in some drainages. Deposits are usually coarser grained in upper reaches and finer grained in distal areas. Deposits derived from thick, shale beds tend to be clayey and matrix supported. Colluvial deposits are unsorted or poorly sorted with weak or no stratification. Clast lithology is variable and depends on locally exposed material. The unit may include talus, landslide deposits, sheetwash deposits, and debris-flow deposits that are too small areally or too indistinct on aerial photographs to be mapped separately. In a few areas within the La Plata Mountains, colluvium is present but not mapped to allow the complex bedrock relationships to be shown. The large deposits of colluvium along Little Deadwood Creek and on the northwest flanks of Baldy Mountain and Ohwiler Ridge likely include areas of shallow bedrock that are not depicted on the map. Exposures in these colluvial areas are very poor; hillslopes have a thick mantle of mixed residuum and organic-rich soils, and have thick vegetative cover. Some areas mapped as colluvium grades into younger fan deposits (Qfy), alluvium and colluvium, undivided (Qac), and sheetwash deposits (Qsw) in some tributary drainages. Maximum thickness is estimated at 40 to 60 ft, but the unit commonly is much thinner. Areas mapped as colluvium are susceptible to future colluvial deposition and locally subject to sheetwash, rockfall, small debris flows, mudflows, and landslides. Fine-grained, low-density colluvium may be prone to collapse upon wetting or loading.

Qls **Landslide deposits (Holocene and Pleistocene)—**Heterogeneous deposits consisting of unsorted, unstratified rock debris, sand, silt, clay, and gravel. Unit includes translational landslides, rotational landslides, earth flows, and extensive slope-failure complexes. Deposits range from active, slowly creeping landslides to long-inactive, middle or perhaps even early Pleistocene landslides. Most landslides involve the Mancos Shale, Dakota Sandstone/Burro Canyon Formation, Menefee Formation, Morrison Formation, or Cliff House Sandstone, and any overlying surficial deposits. Maximum thickness may exceed 100 ft. Landslide deposits may be subject to future movement. Large blocks of rock in these deposits may locally hinder excavation. Deposits may be prone to settlement when loaded. Shallow groundwater may occur within landslide deposits.

Qco **Older colluvium (Pleistocene)—**Occurs on dissected hillslopes, ridgelines, and drainage divides as erosional remnants of formerly more extensive deposits that were transported primarily by gravity and locally by sheetwash processes. Texture, bedding, and clast lithology resemble those of colluvium (Qc). Maximum thickness probably is about 50 ft and commonly is much thinner. Older colluvium on Parrott Peak includes deposits of felsenmeer. Areas mapped as older colluvium generally are not subject to significant future colluviation, except where adjacent to steep, eroding hillslopes. Unit may be subject to collapse, piping, and settlement where fine grained and low in density.

ALLUVIAL AND COLLUVIAL DEPOSITS—Silt, sand, gravel, and clay beneath debris fans, stream channels, flood plains, and adjacent hillslopes in tributary valleys. Depositional processes in stream channels and on flood plains are primarily alluvial, whereas colluvial and sheetwash processes prevail on alluvial fans, on hillslopes, and along the hillslope/valley floor boundary.

Qfy

Younger fan deposits (Holocene)—Includes hyperconcentrated-flow, debris-flow, alluvial, and sheetwash deposits in fans and tributary drainages. Locally the unit may include earthflows or landslides. Younger fan deposits consist of crudely stratified deposits that range from poorly sorted, clast-supported, pebble, cobble, and boulder gravel in a clayey silt or sand matrix to matrix-supported, gravelly, clayey silt. Unit is frequently bouldery, particularly near the heads of some fans. Deposits tend to be finer grained in the distal ends of fans, where sheetwash and mudflow processes become more common. Clasts range from angular to subround. Maximum thickness is about 50 ft. Younger fans are subject to flooding and to future debris-flow, hyperconcentrated-flow, and alluvial deposition. Fine-grained, low-density younger fan deposits may be prone to settlement, piping, and collapse. Unit is a potential minor source of sand and gravel when derived from alluvial deposits.

Qfy

Alluvium and colluvium, undivided (Holocene and late Pleistocene)– Unit chiefly consists of stream-channel, low-terrace, and flood-plain deposits along valley floors of ephemeral, intermittent, and small perennial streams, and of colluvium and sheetwash along valley sides. Locally includes debris-flow deposits or small subdued hills underlain by bedrock. The alluvial and colluvial deposits commonly are interfingered. Unit is poorly to well sorted and ranges from stratified pebbly sand and sandy gravel interbedded with sand (the alluvial component) to poorly sorted, unstratified or poorly stratified clayey, silty sand, bouldery sand, and sandy silt (the colluvial component). Clast lithologies reflect the rocks within the provenance area. Thickness is commonly 5 to 15 ft; maximum thickness is estimated at about 40 ft. Low-lying areas are subject to flooding. Valley sides are prone to colluvial processes, sheetwash, rockfall, and small debris flows. Unit may be subject to settlement, collapse, or piping where fine grained and low in density. Unit is a potential source of sand and gravel.

Qcs

Colluvium and sheetwash deposits, undivided (Holocene and late Pleistocene?)— Composed of colluvium (Qc) on steeper slopes and sheetwash deposits (Qsw) on flatter slopes. This unit is mapped where contacts between the two types of deposits are gradational and difficult to locate. Refer to unit descriptions for colluvium (Qc) and sheetwash deposits (Qsw) for genetic, textural, and lithologic characteristics and for engineering properties and geologic hazards. Unit locally includes debris-flow deposits and small landslide deposits, and possibly lacustrine sediments in the bowl dammed by the moreaine in South Lightner Creek. Thickness averages 10 to 30 ft but may be greater locally.

Qcso

Older colluvium and sheetwash deposits, undivided (Pleistocene)– Includes eroded remnants of formerly more extensive colluvium and sheetwash (Qcs) that now cap hills or ridge lines in the hills south of Highway 160 in the western part of the quadrangle. Deposits lie 20 to 200 ft above adjacent drainages. It resembles colluvium and sheetwash (Qcs) in texture and lithology but is much older. Maximum thickness probably 40 to 60 ft. Mapped area is probably not subject to future deposition.

Qcso

Older alluvium and colluvium, undivided (Pleistocene)– Includes a single remnant of alluvium and colluvium on the west side of Deadwood Creek about one mile above the confluence with the La Plata River. Deposit is about 30 to 40 ft above Deadwood Creek. Unit is texturally similar to alluvium and colluvium, undivided (Qac). Clast lithology is chiefly diorite porphyry, with lesser percentages of sandstone and siltstone. Thickness estimated at 10 to 20 ft. Unit may be a potential source of sand and gravel.

Qdi **Diamicton (late? Pleistocene)—**Includes several remnants of deposits along the east side of the La Plata River north and south of the mouth of Deadwood Creek. Unit is very poorly exposed. Based on float, it appears to be chiefly a heterogeneous and matrix-supported deposit of poorly sorted, angular to subround pebbles, cobbles, and occasional boulders in a silty, sandy, or clayey matrix. Clasts are mostly light-brown to light-gray sandstone, gray shale and siltstone, diorite porphyry, and greenish mudstone. Diamicton is a nongenetic name for poorly sorted terrestrial sediment whose origin is uncertain. The lack of associated landforms and poor or nonexistent exposures lead to the uncertainty. The diamicton in the Hesperus quadrangle is probably of glacial or mass-wasting origin. Maximum thickness is estimated at 20 ft. Unit may be a source of gravel.

Qfo **Older fan deposits (late or middle Pleistocene)—**Includes several remnants of a formerly more extensive fan deposited by Cherry Creek near the west edge of the quadrangle. Unit is primarily matrix-supported and is genetically and texturally similar to younger fan deposits. Clasts average around 75 percent diorite porphyry and syenite porphyry, 15 percent light-brown to light-gray sandstone, and 10 percent red-brown sandstone and siltstone, and they are slightly to moderately weathered. Cherry Creek has eroded as much as about 80 ft into this deposit. Older fan deposits are estimated to be a maximum of about 80 ft thick. Unit is a source of sand and gravel and has been mined in the recent past.

GLACIAL DEPOSITS—Gravel, sand, silt, and clay deposited by or adjacent to glacial ice in moraines in the La Plata River valley.

Qm_1 **Younger moraine deposits (late Pleistocene)—**Heterogeneous deposits of chiefly silty to bouldery sediments deposited by or adjacent to glacial ice near the mouth of La Plata Canyon. Unit was apparently largely deposited in ground, lateral, and end moraines. It is very poorly exposed, but appears to be dominantly matrix-supported, pebbly and cobbly silt with occasional boulders. Clasts are unweathered or only slightly weathered, subround to subangular, and consist largely of diorite porphyry, monzonite porphyry, sandstone, and siltstone. These deposits are tentatively correlated with the till and diamicton of Animas City moraines in the Animas River valley (Johnson and Gillam, 1995; Gillam, 1998; Carroll and others, 1999), and likely are close in age to Pinedale and other late-Wisconsin moraines which formed about 12 to 35 ka (Richmond, 1986). Younger moraine deposits are estimated to be as much as about 50 ft thick in lateral moraines and 15 to 20 ft thick in ground moraine. Unit may contain placer gold (Eckel, 1949) and may be a source of sand and gravel.

Qm_2 **Intermediate moraine deposits (late? middle Pleistocene)—**Heterogeneous deposits of chiefly silty to bouldery sediments deposited by or adjacent to glacial ice near the mouth of La Plata Canyon. The associated landforms suggest most of the intermediate moraine deposits were lateral or ground moraines. Unit is poorly exposed. Intermediate moraine deposits appear to be texturally and lithologically similar to younger moraine deposits (Qm_1), but are slightly more weathered. One of the terraces included in terrace alluvium two (Qt_2) is graded to intermediate moraine deposits. This unit is tentatively correlated to till and diamicton of Spring Creek moraines in the Animas River valley (Gillam and others, 1984; Gillam, 1998; Carroll and others, 1999). The Spring Creek moraines are thought to correlate to Bull Lake, Eowisconsin, and other moraines in the Rocky Mountains that formed during marine oxygen-isotope stages 5 and 5d-5b (Richmond and Fullerton, 1986; Carroll and others, 1999). Gillam (1998) suggested these moraines range in age from about 85 to 160 ka. Intermediate moraine deposits are estimated to be as much as 50 to 60 ft thick based on the landforms associated with the unit, but the base of the deposit was not observed during this study. Intermediate moraine deposits may contain placer gold (Eckel, 1949) and may be a source of sand and gravel.

Qm_3 **Older moraine deposits (middle Pleistocene)—**Heterogeneous deposits of chiefly silty to bouldery sediments deposited by or adjacent to glacial ice near the mouth of La Plata Canyon. These deposits were formed as lateral, terminal, and ground moraine. They are the outermost and oldest preserved moraines that were recognized in the La Plata River valley in Hesperus quadrangle. The only exposure of this unit noted during this project is in the headscarp of the recent landslide near the north quarter-corner of section 32, T. 36 N., R. 11 W. Most of the material exposed at this location is poorly bedded, poorly sorted, matrix-supported, gravelly, sandy silt. Clasts range from angular to round cobbles, pebbles, and occasional boulders up to 4 ft in diameter that are generally moderately weathered. Clast lithologies include about 70 percent light-brown, tan, and red-brown sandstone, 25 percent various types of intrusive rocks derived from the La Plata Mountains, and 5 percent conglomeratic sandstone.

The correlation of older moraine deposits in the Hesperus quadrangle to those in the Animas River valley is uncertain. The highest terrace included in terrace alluvium three is herein correlated to a terrace that is overlain by the 600 ka Lava Creek B ash in the Kline quadrangle (Scott and Moore, 1981), but lower Qt_3 terraces may correlate with terraces associated with the Durango moraines. The older moraine deposits near the mouth of La Plata Canyon are graded to one of the Qt_3 terraces; therefore they are equivalent in age. Unfortunately, the age of this particular terrace in uncertain. Its stratigraphic and age relationship to the terrace overlain by the 600 ka Lava Creek B ash is unknown. Therefore the older moraine deposits may correlate with the till and diamicton of Durango moraines in the Animas River valley that are thought to be around 250 to 275 ka (Gillam, 1998; Carroll and others, 1999) or to moraines that predate the 600 ka Lava Creek B ash. Unit is only 10 to 20 ft thick where exposed in the headscarp of the recent landslide, but it may be thicker beneath the crest of the moraine. Intermediate moraine deposits may contain placer gold (Eckel, 1949) and may be a source of sand and gravel.

Qfy

Undifferentiated moraine deposits (late or middle? Pleistocene)—Includes a single deposit along South Lightner Creek that is associated with an arcuate, steep-sided landform that parallels the creek near the northeastern corner of the quadrangle. The geomorphic characteristics of this landform suggest it is a lateral moraine. A nearly closed topographic depression lies on the east side (valley-wall side) of the arcuate ridge. We interpret the topographic depression as a tributary valley that was dammed by the lateral moraine and subsequently partially filled with locally derived colluvium, sheetwash deposits, and possibly lacustrine sediments. Large subangular boulders and cobbles of intrusive rock occurred as float on the arcuate, steep-sided ridge thought to be a lateral moraine, but the materials underlying it are not exposed. If this landform is a moraine, then the associated deposits are likely similar to younger moraine deposits (Qm_1). Clast lithology may be somewhat different, as the provenance for this deposit is South Lightner Creek. The age relationship with moraines in the La Plata River valley is unknown, but based on its position adjacent to the creek and height above it, the deposit is probably late Pleistocene or, less likely, middle Pleistocene. Deposit may be a source of sand or gravel.

PERIGLACIAL DEPOSITS—Sediments deposited in cold environments largely by solifluction

Qs

Solifluction deposits (Holocene and late Pleistocene)—Thin deposits resulting from the slow downslope flowage of water-saturated materials, probably over frozen ground. The deposits occur on the southwest end of Parrott Peak. The unit is not well exposed in outcrops; it probably consists of angular to subangular boulders, cobbles, and pebbles in sand or silt matrix. Areas mapped as solifluction deposits locally include patterned ground. Solifluction deposits may be prone to future movement. Shallow ground water may be associated with solifluction deposits. Maximum thickness is estimated at 10 to 15 ft.

UNDIFFERENTIATED DEPOSITS

Q

Undifferentiated surficial deposits (Quaternary)—Shown only on cross section

BEDROCK

IGNEOUS ROCKS—

TKs

Syenite porphyry (Upper Cretaceous or Paleocene)– A stock of light-brown to medium-gray syenite porphyry is exposed west of Parrott Peak. The rock weathers reddish brown to light tan and has a pronounced hiatal porphyritic texture defined by laths and blades of plagioclase up to 1 cm in length. Phenocrysts and microphenocrysts of plagioclase (An_{18} to An_{30}), hornblende recrystallized to aegerine-augite, apatite, sphene, and opaque minerals make up between 10 to 30 percent of these rocks.

The phenocrysts are set in a very fine-grained matrix composed mostly of feldspar that is altered and recystallized to sericite, epidote, clay, and calcite. Aegerine-augite is bright green and forms mantles of small subequant crystals around brownish-green hornblende crystals. This indicates dehydration and alkali enrichment during the final stages of emplacement and crystallization. The color index of these rocks varies from 3 to 10 percent, based on the classification system of Barker (1979). In some samples the mafic minerals are almost completely altered to chlorite and iron oxides. Preliminary results of an Ar^{40}/Ar^{39} age determination on a sample of syenite porphyry from this stock indicates an age of about 68 Ma (Lisa Peters, New Mexico Institute of Mining and Technology, 2000, written communication). Several prospects pits are located within this unit along east-west trending fracture zones. It is a potential source of riprap.

TKl **Lamprophyre (Upper Cretaceous or Paleocene)–** Dark-green to greenish-black porphyritic rock with phenocrysts of hornblende 3 to 5 mm long set in a fine-grained groundmass composed chiefly of hornblende and plagioclase. Phenocrysts make up about 10 to 30 percent of the rock. Although lamprophyres are widespread in the northern part of the La Plata Mountains, only a single north- to northwest-trending dike of lamprophyre was found in the northeastern part of the quadrangle. The dike is on the southeast side of Ohwiler Ridge in upper Deadwood Creek. This lamphrophyre dike cuts a stock of diorite porphyry.

TKm **Monzonite porphyry (Upper Cretaceous or Paleocene)–** Light-tan to light-gray monzonite porphyry exposed near the mouth of Burnt Timber Creek. Weathers reddish brown to brown. Unit is restricted primarily to an irregularly shaped stock and nearby dikes. These rocks consist of 20 to 60 percent phenocrysts and microphenocrysts (0.5 to 6 mm in size) of feldspar, augite, hornblende, apatite, sphene, and opaque minerals that are set in a very fine-grained to fine-grained, feathery groundmass of altered feldspar. The color index ranges from 5 to 20 percent (Barker, 1979). Feldspar phenocrysts consist of laths and stubby subequant crystals of andesine (An_{30} to An_{40}) and blocky subequant crystals of orthoclase. Typically the plagioclase is recrystallized and highly altered to masses of epidote, sericite, and calcite. The plagioclase commonly has a pronounced oscillatory zoning indicative of rapid cooling and disequilibrium crystallization. Orthoclase phenocrysts typically show complete or near complete alteration to sericite and clay. Proportions of plagioclase and orthoclase are variable, but in most samples there is a higher percentage of plagioclase. Augite and hornblende crystals are subhedral to euhedral and make up less than 5 to 30 percent of these rocks. Hornblende commonly mantles augite crystals, indicating late-stage volatile enrichment and deuteric recystallization. Alteration of hornblende and augite to chlorite occurs locally. Mafic and opaque minerals are also commonly oxidized to limonite and hematite. Microscopic veins of quartz and calcite were noted in one sample. Opaque minerals include magnetite and pyrite. Unit is a potential source of riprap.

TKd **Diorite porphyry (Upper Cretaceous or Paleocene)–** Light-gray dikes, sills, and stocks of diorite porphyry that weather to a medium-gray or white to brown color. Diorite porphyry is the dominant type of intrusive rock in the Hesperus quadrangle. These rocks consist of 10 to 65 percent phenocrysts (1 to 10 mm in size) of subhedral to euhedral crystals of plagioclase (An_{20} to An_{25}), hornblende, opaque minerals, apatite, and sphene. The color index ranges from 5 to 35 percent based on the classification system of Barker (1979). Phenocrysts of subhedral to euhedral orthoclase and anhedral quartz occur as minor constituents in some samples. Plagioclase crystals occur in laths to tabular, subequant crystals, typically have a pronounced oscillatory zoning, and locally define a weak flow lineation. The groundmass in most samples is generally a feathery to granular mass of recrystallized and altered feldspar. Deuteric recrystallization and alteration are developed to varying degrees in all samples. Hornblende is typically altered to masses of chlorite, calcite, and minor biotite while feldspar phenocrysts are recrystallized to aggregates of sericite, clay, calcite, and epidote. Numerous joints that are interpreted as cooling features typically cut outcrops of diorite porphyry.

The diorite porphyry intrusive rocks commonly contain cogenetic hornblende-rich inclusions and xenoliths of Proterozoic granite and felsic to mafic schist and gneiss. Inclusions and xenoliths range from 1 cm to tens of centimeters in maximum dimension. $_{40}Ar/_{39}Ar$ age determinations on diorite porphyry and hornblendite inclusions from sites outside the map area are about 65 Ma. Dikes and sills of diorite porphyry have a close spatial relationship to zones of mineralization in the La Plata Mountains. Unit is a potential source of riprap.

SEDIMENTARY ROCKS—

Kl

Lewis Shale (Upper Cretaceous)—Dark-gray, fissile shale containing thin sandstone beds at top and gray, rusty-weathering concretionary limestone in the lower part. Altered volcanic ash beds within the Lewis Shale, most notably the Huerfanito Bentonite Bed (dated at 75.76 Ma by Fasset amd Steiner, 1997), have been used as time-stratigraphic markers throughout the San Juan Basin (Fassett and Hinds, 1971, Fassett and Steiner, 1997). The unit weathers easily and is generally covered by surficial deposits. Where mapped along terrace scarps or terrace risers, the unit is commonly concealed by a thin veneer of colluvium that contains rounded clasts of river gravel derived from overlying terrace alluvium. The contact with the underlying Cliff House Sandstone is conformable and usually gradational. The Lewis Shale was deposited in a low-energy, off-shore, marine environment (Fassett and Hinds, 1971). Formation thickness averages about 1,800 ft in adjacent areas, but only the lower part of the formation is present in the Hesperus quadrangle. It is a reservoir for natural gas in the San Juan Basin. The Lewis Shale is prone to landsliding, especially along the margins of gravel-capped mesas that are underlain by the formation. The Lewis Shale is highly susceptible to shrink-swell problems where it contains expansive clays.

Mesaverde Group (Upper Cretaceous)—Consists of three mappable formations in the Hesperus quadrangle, which, in descending order, are the Cliff House Sandstone, Menefee Formation, and Point Lookout Sandstone. These formations are distinguished primarily by the carbonaceous shale and coal within the Menefee Formation and the presence of Ophiomorpha burrows in the Cliff House Sandstone and Point Lookout Sandstone. The Point Lookout Sandstone and resistant sandstone beds in the Menefee Formation locally form prominent cliffs in the quadrangle.

Qfy

Cliff House Sandstone—Interbedded sequence of thin beds of moderately hard, yellowish-orange to white, very fine- to fine-grained calcareous sandstone and easily eroded light-gray mudstone, siltstone, and silty shale. Sandstone beds contain locally abundant Ophiomorpha burrows. The sandstone beds weather to yellow brown or light red brown, forming a rusty-colored outcrop that sharply contrasts with the drab colors of the underlying Menefee Formation. The Cliff House Sandstone caps many of the broad, rounded ridges in the southwestern part of the quadrangle. There commonly is a subtle but consistent slope break at the contact with the Menefee Formation.

Individual sandstone beds within the Cliff House Formation thicken west of the quadrangle. Barnes and others (1954) described sandstone beds up to 14 ft thick on Weber Mountain south of the town of Mancos. In Mesa Verde National Park sandstone beds are as much as 50 to 70 ft thick. To the east shale and siltstone beds thicken and sandstone beds thin. The Cliff House Sandstone is usually poorly exposed except in road cuts and other excavations. Contact with the underlying Menefee Formation appears to be conformable and gradational in most of the quadrangle. To the west on Barker Dome Barnes and others (1954) described local intertonguing of the Cliff House Sandstone and Menefee Formation. Stratigraphic studies utilizing data from coal exploration drill holes suggest similar intertonguing may occur in Hesperus quadrangle (Steve Korte, 1999, oral communication). This intertonguing relationship is depicted on cross section A-A′. Zapp (1949) also suggested that such intertonguing may be developed in the formation between the coal mines in Hay Gulch and those near the town of Hesperus.

The Cliff House Sandstone is a transgressive, shallow marine unit rapidly deposited on the upper shoreface zone of a barrier-island beach front (Siemers and King, 1974). Thickness in the quadrangle averages about 400 ft and may locally exceed 440 ft. Formation thins east of Hesperus quadrangle. Shale beds in the Cliff House Sandstone may have moderate to high swell potential. The formation is an important natural gas reservoir and producer in the San Juan Basin.

Kmf

Menefee Formation—Interbedded gray, brown, and black carbonaceous shale and siltstone, light-gray, brown, and orange-brown, locally lenticular, crossbedded sandstone, and coal. Locally includes burnt rock and clinker resulting from burning of coal beds within the formation. Sandstone beds are commonly well cemented and locally form prominent cliffs. They also contain ripple marks and sometimes have abundant organic debris. Contact with the underlying Point Lookout Sandstone is conformable, but often sharp. It is placed at the base of the lowest coal or carbonaceous shale bed. The Menefee Formation was deposited in a coastal-plain environment (Aubrey, 1991). Thickness is highly variable, ranging from about 220 to 325 ft, but in general the formation is thickest in the southwestern part of the quadrangle and thinner along the eastern edge. The variation is partly due to syn-depositional factors, such as the possible intertonguing between the Menefee and Cliff House Sandstone, but also to differential compaction of the sand, clay, and especially the peat beds during lithification. Thickness variations are also related to volume loss due to combustion of coal beds.

Significant coal resources are present within the Menefee Formation. Individual coal beds are locally up to about 11 ft thick, but typically are a maximum of 5 to 6 ft thick. Nearly all mines in Hay Gulch were developed in a laterally persistent coal bed that occurs immediately below the Cliff House Sandstone. This bed was called the Peacock seam in the older, now abandoned mines (Boreck and Murray, 1979). However, National King Coal, LLC, which operates the only active coal mine in the quadrangle, refers to this bed as the "A" seam. Mines in the vicinity of the town of Hesperus mined coal beds in the middle part of the formation. Stratigraphic relationships between these coal beds in the middle part of the formation and the "A" seam in Hay Gulch that lies at the top of the formation are not clear. The geometry of the possible intertonguing between the Menefee Formation and Cliff House Sandstone is poorly understood, which further obfuscates the correlation of these coal beds.

Subsidence of the land surface may occur above underground mines where coal was extracted from the Menefee Formation. Burning coal beds and seepage of methane or hydrogen sulfide from coal outcrops can be hazardous. Thick sandstone beds in the formation may cause local rockfall hazards.

Kplu

Point Lookout Sandstone, undivided—Shown only on cross section. This formation is subdivided into two lithostratigraphic units, a massive part and lower part, on the basis of the relative amounts of sandstone and shale. The two sequences are mappable lithologic units in the quadrangle, each with different engineering geology characteristics. West of the quadrangle, near the town of Mancos, Barnes and others (1954) and Condon (1990) described intertonguing relationships between the massive and lower parts, including an area where massive sandstone beds occur at both the top and base of the formation.

The formation consists of sandstone lenses that are stacked in an imbricate pattern and separated by shale and siltstone of varying thickness. The younger beds lie to the northeast. Barnes and others (1954) traced individual sandstone beds and discovered the sandstone lenses were thickest in the massive part and thinner in the lower part. Within the Hesperus quadrangle the sandstone beds in the Point Lookout Sandstone become thinner and shale becomes more common in the lower part of the formation. For this study the basal formation contact is arbitrarily placed at the base of the lowest 1-ft-thick sandstone bed or at the point where the strata contain more than 50 percent shale over a 6 ft stratigraphic interval.

The contact with the underlying Mancos Shale is conformable and gradational.The formation was deposited in a coastal shoreline environment as a deltaic plain and mouthbar depositional sequence in the Durango delta (Wright, 1986, Wright-Dunbar and others, 1992). The Point Lookout Sandstone represents an eastward prograding shoreline between the sea in which the Mancos Shale was deposited and the coastal plain where the Menefee Formation was accumulating. Thickness ranges from about 280 to 375 ft. The Point Lookout Sandstone is an important reservoir and producer of natural gas in the San Juan Basin.

Kplm

Massive part of Point Lookout Sandstone—Thick, massive beds of light-gray to yellowish-gray or brown, quartzose sandstone, with very minor interbeds of dark-gray shale. The sandstone is fine to medium grained, cross laminated, well sorted, and cemented with calcite. Locally the massive part contains Ophiomorpha burrows. This unit locally forms prominent cliffs. Thickness ranges from about 40 to 80 ft. The massive part of the Point Lookout Sandstone may pose rockfall hazards where exposed in steep cliffs.

Kpl

Lower part of Point Lookout Sandstone—Sequence of interbedded thin sandstone and shale beds that are gradational between the massive part of the Point Lookout Sandstone and the Mancos Shale. Sandstone beds are less than one ft thick and consist of light-gray to yellowish-gray or brown, quartzose sandstone. Shale beds are light to dark gray, fossiliferous, and carbonaceous, and become more abundant towards the base of the unit. The lower part of the Point Lookout Sandstone is usually poorly exposed. Contact with underlying Mancos Shale is conformable and is arbitrarily placed at the base of the lowest 1-ft-thick sandstone bed or where the strata contain more than 50 percent shale in a six-ft-thick stratigraphic interval. Thickness averages 250 to 300 ft. Shale beds in the lower part may have high swell potential. It is prone to landsliding, and soil slips are common in residuum and colluvium derived from the unit.

Km

Mancos Shale (Upper Cretaceous)—Dark-gray to black shale and silty shale, dark-gray to blue-gray argillaceous limestone, and calcarenite with thin beds of bentonite. Unmapped landslide deposits locally overlie the Mancos Shale. Yellowish-brown to dark-brown weathered concretions form within the calcareous basal part of the formation. The Mancos Shale is generally very poorly exposed within the quadrangle. West of the quadrangle in and near Mesa Verde National Park, Leckie and others (1997) subdivided it into eight members. In ascending order, these members are the Graneros, Bridge Creek, Fairport, Blue Hill, Juana Lopez, Montezuma Valley, Smoky Hill, and Cortez members. A few of these members were recognized in the scattered and limited exposures in the Hesperus quadrangle but were not mapped separately. Leckie and others (1997) described 188 bentonite beds, most of which are less than 4 inches thick, within the Mancos Shale west of the quadrangle. They occur throughout the formation but are most abundant in the lower one-fourth. The contact with the underlying Dakota Sandstone is conformable and perhaps intertongued locally. The Mancos Shale was deposited in a low-energy, marine environment. Total thickness of the Mancos Shale is about 2,000 to 2,400 ft. The Mancos Shale is prone to landsliding. Bentonitic beds may cause expansive soil and heaving bedrock problems. Unit is rich in sulfate, which can be corrosive to concrete and may affect the quality of groundwater.

Kdb

Dakota Sandstone (Upper Cretaceous) and Burro Canyon Formation (Lower Cretaceous), undivided—Dakota Sandstone is composed of light- to medium-gray, light- to medium-brown, and yellowish-brown, fine- to coarse-grained sandstone and minor conglomeratic sandstone and conglomerate that is interbedded with dark- to medium-gray siltstone, carbonaceous shale, and thin coal beds. The uppermost part of the Dakota includes a thin, thinly bedded, marine sandstone informally called the Paguate member (Don Owen, 1999, oral communication). Conglomerate clasts in the Dakota Sandstone usually are granules and pebbles of chert and quartz. The Burro Canyon Formation consists of very light-brown to very light-gray, medium- to coarse-grained sandstone, chert-pebble conglomerate, and grayish-green, non-carbonaceous claystone. The absence of coal and carbonaceous shale and the presence of green claystone and white (kaolinitic?) clasts and cement in the Burro Canyon Formation are the primary characteristics used to distinguish it from the Dakota Sandstone (Turmelle, 1979). The white lasts are rich in clay and mica and contain relict features suggestive of altered phenocrysts.

The Dakota Sandstone and Burro Canyon Formation are lumped into a single map unit because surficial deposits usually either conceal the contact between the two formations, or it occurs in a near vertical cliff or very steep hillslope and is not possible to depict on a map at a scale of 1:24,000. Unmapped colluvium or landslide deposits locally overlie the unit. Lucas and Anderson (1997a) stated that the Burro Canyon Formation is synonymous with Cedar Mountain Formation. The Burro Canyon Formation and Dakota Sandstone are separated by a disconformity with local erosional relief (Aubrey, 1991; Don Owen, 1999, oral communication). In places much and perhaps all of the Burro Canyon Formation was erosionally removed prior to deposition of the Dakota Sandstone. The upper part of the Dakota Sandstone was deposited in coastal swamp, lagoon, and beach environments, whereas the lower part of the Dakota Sandstone and the Burro Canyon Formation were likely deposited in a fluvial environment. The combined thickness of the two formations averages 180 to 250 ft in the quadrangle.

The Dakota Sandstone and Burro Canyon Formation generally serve as good foundation material, although excavations into well-cemented beds may require blasting. Where exposed in cliffs and steep hillslopes, this unit causes rockfall hazards, including massive rock topples like the July 5, 1998 event on the east side of the Animas River valley that involved about 50,000 cubic yards of rock (Carroll and others, 1999). Shear fractures commonly act as failure planes for rockfalls and rock topples. The unit is prone to landsliding along shale beds within the formation. The Dakota Sandstone is an oil and gas reservoir in parts of the San Juan Basin.

Jm

Morrison Formation (Upper Jurassic)— Consists of an upper member called the Brushy Basin Member and a lower member known as the Salt Wash Member, but these were not mapped separately in this quadrangle due to poor exposures. In several areas the Morrison Formation is overlain by thin, unmapped landslides and small soil slips. The Brushy Basin Member is chiefly greenish-gray, occasionally reddish-brown, bentonitic mudstone and claystone containing thin beds of very fine-grained sandstone and rare conglomeratic sandstone. It conformably overlies and perhaps intertongues with the Salt Wash Member (Condon, 1990). The Salt Wash Member is mainly light-gray to white, fine- to medium-grained, locally silicified, lenticular sandstone interbedded with thin beds of greenish-gray mudstone. The Salt Wash Member conformably overlies the Junction Creek Sandstone.

The depositional environment of the Brushy Basin Member is subject to debate. Condon (1990) reported it was deposited in shallow lacustrine and fluvial environments. Turner and Fishmann (1991) suggested that much of the Brushy Basin was deposited in a single ancient, alkaline, saline lake called Lake T'oo'dichi'. Anderson and Lucas (1997a; 1997b) preferred a depositional model involving numerous smaller lakes on a vast floodplain. Thickness of the Brushy Basin Member is estimated at 150 to 200 ft. The Salt Wash Member was deposited in a fluvial environment (Condon, 1990) and is about 200 to 300 ft thick. Bentonitic beds within the formation may be prone to swelling soil problems. The Brushy Basin Member may be subject to landsliding where exposed on steep hillslopes or on dip slopes. The Salt Wash Member has yielded large amounts of uranium in the region, although no known radioactive occurences have been reported in the quadrangle (Nelson-Moore and others, 1978).

KJdm

Dakota Sandstone, Burro Canyon Formation, and Morrison Formation, undivided (Upper and Lower Cretaceous and Upper Jurassic)— Shown only in northwest part of quadrangle where poor exposures limit recognition of contacts.

Jjc

Junction Creek Sandstone (Middle Jurassic)— Light-gray to tan, highly cross-bedded to massive, fine- to coarse-grained, eolian sandstone. The Junction Creek Sandstone usually is poorly exposed in the quadrangle. Within the La Plata Mountains the formation is often obscured by blocky deposits of felsenmeer derived from it. It is correlative with the Bluff Sandstone in the Four Corners Region and southeastern Utah (O'Sullivan, 1997; Lucas and Anderson, 1997b). The Junction Creek Sandstone conformably overlies the Wanakah Formation. It was deposited chiefly in an eolian environment (Peterson, 1972). Thickness averages about 100 ft. It may pose rockfall hazards where exposed in steep cliffs.

Jw

Wanakah Formation (Middle Jurassic)— Consists of two members: an upper member composed mostly of white to tan, reddish-orange, and reddish-brown, very fine- to fine-grained sandstone and reddish-brown to greenish-gray mudstone; and a lower member, the Pony Express Limestone Member, consisting of medium- to dark-gray, very thin-bedded to laminated, micritic, oolitic, and algal limestone. The Pony Express Limestone Member locally is brecciated and fractured, and contains thin sandstone dikes that were probably injected into it from the underlying Entrada Sandstone. The formation is very poorly exposed in the quadrangle; only the Pony Express Limestone Member locally forms outcrops. The upper member of the Wanakah Formation and the Pony Express Limestone Member are probably correlative with the Summerville Formation in the Four Corners region and in part with the Todilto Formation in New Mexico. The gypsiferous part of the formation is not present in the Hesperus quadrangle. The Wanakah Formation conformably overlies the Entrada Sandstone. Condon (1990) suggested the upper member of the Wanakah Formation was deposited in sabkha and marginal marine environments and the Pony Express Limestone Member was of restricted marine origin. Lucas and Anderson (1997b) described the upper member (Summerville Formation) as being deposited in quiet, ephemeral shallow water on an arid coastal plain of very low slope and relief. Thickness of the upper member ranges from about 40 to 70 ft, while the Pony Express Limestone Member is about 3 to 7 ft thick. North of Durango this member is represented by a 2- to 5-ft-thick oolitic limestone (Baars and Ellingson, 1984), whereas to the south it includes a 5- to 15-ft-thick limestone bed and a bed of gypsum up to about 15 ft thick (Condon, 1990). The Pony Express Limestone Member hosts many replacement-type ore deposits in the La Plata Mountains.

Je

Entrada Sandstone (Middle Jurassic)— Light-gray to white, sometimes orangish-gray, fine- to medium- to coarse-grained, highly crossbedded sandstone that is locally coarse grained or conglomeratic at the base of the formation. The Entrada Sandstone typically has prominent large-scale cross bedding. It occasionally forms good outcrops, but commonly is veneered by colluvium or residuum. The Entrada Sandstone unconformably overlies the Dolores Formation and was deposited in an eolian environment. Thickness averages about 250 ft. Where exposed in cliffs, the Entrada Sandstone may cause rockfall hazards. It hosts mineralized veins in the mountainous part of the quadrangle (Eckel, 1949; Neubert and others, 1992) and has yielded uranium and vanadium in the adjacent Durango West quadrangle.

Jwe

Wanakah Formation and Entrada Sandstone, undivided (Middle Jurassic)— Mapped only on the west side of the La Plata River near Mayday where poor exposures prevent recognition of the contact between the two formations.

TRPdc

Dolores and Cutler Formation, undivided (Upper Triassic and Lower Permian)— Includes both the Upper Triassic Dolores Formation and Lower Permian Cutler Formation because the contact between the two units is generally concealed by surficial deposits or heavy vegetation in the quadrangle. The Dolores Formation is mostly dark-reddish-brown to purplish-red shale and siltstone and light-brown, gray, and reddish-brown lenticular sandstone and limestone-pebble conglomerate containing rare thin limestone beds. Locally it is well exposed on steep hillslopes, but typically it is partly or completely covered. Lucas and others (1997b) correlated the Dolores Formation with an upper member (Rock Point Formation), middle member (Painted Desert Member of the Petrified Forest Formation), and lower member (Moss Back Formation) of the Chinle Group strata on the Colorado Plateau. The Cutler Formation consists of medium- to dark-reddish-brown, medium-gray, and medium- to dark-brown sandstone, arkosic sandstone, and arkosic conglomerate and reddish-brown to purplish-brown shale and siltstone containing occasional limestone-pebble conglomerate and rare thin limestone beds.

The Dolores Formation unconformably overlies the Cutler Formation. Although the contact between the Dolores and Cutler is a major unconformity, it is not easily recognizable even where exposures are good. In the Durango area Kirkham and others (1999) placed the contact at the base of the first limestone-pebble conglomerate that occurred stratigraphically above the highest arkosic bed in the Cutler Formation. This limestone-pebble conglomerate locally contains crocodilian teeth and bone fragments, although none were found in the Hesperus quadrangle. The Dolores Formation was deposited in fluvial and lacustrine environments (Condon, 1990) , whereas the Cutler Formation was deposited in fluvial and alluvial-fan environments (Campbell, 1976; 1979; 1980). Thickness of the Dolores Formation averages about 500 to 600 ft. Only the upper part of the Cutler Formation is exposed in the Hesperus quadrangle; in nearby areas it is about 2,000 to 2,500 ft thick. The Dolores and Cutler Formations host ore-bearing veins in the mountainous parts of the quadrangle. Both formations may be prone to rockfall hazards where exposed in steep cliffs.

GEOCHEMISTRY OF IGNEOUS ROCKS

Representative samples of felsic to intermediate intrusive rocks from the map area were analyzed by Chemex Labs, Inc. for major oxides and several trace elements using the X-ray fluorescence method. No analyses were obtained for the single lamprophyre dike. Geochemical analytical data are reported in table 1. To facilitate the geochemical classification of these rocks, the normative mineralogy for these samples was calculated (Table 2).

Felsic to intermediate plutonic rocks in the Hesperus Quadrangle have distinct chemical signatures. They plot in either the alkali syenite or alkali syenodiorite fields on the total alkali-silica plot of Cox and others (1979), and they are classified as trachyte and trachyandesite on the total alkali-silica classification diagram of Le Maitre and others (1989). The potassic-alkaline signatures of these rocks are also evident on the various chemical classification diagrams that are summarized in Table 3.

Table 1. Whole-rock XRF chemical analyses (performed by Chemex Labs, Inc.)

	Rock	Percent											
Sample	Type	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	Total
LM-44-99	syenite	59.74	0.30	19.30	2.68	0.15	0.34	2.71	6.11	5.81	0.08	1.69	98.91
LM-45-99	syenite	58.75	0.38	19.61	3.06	0.16	0.49	3.27	6.25	5.19	0.12	2.06	99.34
LM-49-99	syenite	59.37	0.31	19.56	2.65	0.15	0.34	2.79	6.32	5.65	0.10	2.03	99.27
LM-47-99	diorite	63.00	0.42	17.65	4.24	0.11	1.01	3.86	5.70	2.98	0.19	0.61	99.27
LM-52-99	diorite	59.55	0.64	16.62	6.52	0.16	2.36	4.60	4.72	2.78	0.29	1.64	99.88
LM-65-99	diorite	61.09	0.47	16.57	3.76	0.09	0.71	3.77	4.47	4.33	0.20	4.31	99.77
LM-57-99	monzonite	66.28	0.36	15.13	2.78	0.07	0.77	1.89	3.16	8.35	0.13	0.65	99.57
LM-58-99	monzonite	62.78	0.45	17.88	2.08	0.05	1.01	3.90	6.18	3.97	0.19	0.52	99.01
LM-60-99	monzonite	64.73	0.33	17.18	1.79	0.08	0.58	3.13	5.13	5.35	0.11	0.40	98.81

	Rock	ppm					
Sample	Type	Ba	Rb	Sr	Nb	Zr	Y
LM-44-99	syenite	1,880	92	2,570	26	273	22
LM-45-99	syenite	2,090	82	2,610	30	267	24
LM-49-99	syenite	1,775	90	2,200	28	276	22
LM-47-99	diorite	925	58	1,295	20	159	24
LM-52-99	diorite	890	52	1,220	16	159	24
LM-65-99	diorite	1,240	92	834	18	180	30
LM-57-99	monzonite	705	108	568	20	144	24
LM-58-99	monzonite	1,060	76	1,145	18	156	26
LM-60-99	monzonite	1,115	86	1,055	24	201	28

Relative to the diorite porphry and monzonite porphyry samples, the syenite porphyry samples are lower in SiO_2 and higher in total alkalies, aluminum, and strontium. The syenitic rocks are also nepheline normative and have low normative "An" numbers (percent anorthite; see Table 2). The alkali enrichment in these rocks is reflected in the late-stage sodium-rich pyroxene that crystallized around hornblende. High strontium concentrations reflect the abundance of plagioclase as phenocrysts and in the groundmass.

Table 2. Normative mineralogical anaylses for igneous rocks (values are in percentages). % An = an/an + ab; Q = quartz; or = orthoclase; ab = albite; ne = nepheline; di = diopside; hy = hypersthene; wo = wollastanite; il = ilmenite; hem = hematite; ti = sphene; ap = apatite; pero = perovskite

	Rock							Percent							
Sample	Type	An	Q	or	ab	an	ne	di	hy	wo	il	hem	ti	ap	pero
LM-44-99	syenite	15.16	0	34.33	45.19	8.07	3.52	1.83	0	0.85	0.32	2.68	0	0.19	0.22
LM-45-99	syenite	18.33	0	30.37	45.09	10.13	4.22	2.63	0	0.52	0.34	3.06	0	0.28	0.34
LM-49-99	syenite	15.71	0	33.39	44.61	8.32	4.80	1.83	0	0.85	0.32	2.65	0	0.23	0.24
LM-47-99	diorite	22.21	10.0	17.61	48.23	13.77	0	2.41	1.39	0	0.24	4.24	0.73	0.44	0
LM-52-99	diorite	28.54	9.97	16.43	39.93	15.95	0	2.62	4.66	0	0.34	6.52	1.12	0.67	0
LM-65-99	diorite	24.63	11.0	25.59	37.82	12.36	0	2.92	0.41	0	0.19	3.76	0.90	0.46	0
LM-57-99	monzonite	8.36	12.4	49.34	26.74	2.44	0	3.98	0.74	0	0.15	2.78	0.69	0.30	0
LM-58-99	monzonite	15.13	4.21	23.46	52.29	9.32	0	5.43	0	0.19	0.11	2.08	0.97	0.44	0
LM-60-99	monzonite	15.65	8.61	31.62	43.40	8.05	0	3.12	0	0.80	0.17	1.79	0.59	0.25	0

Samples of monzonite porphyry have the highest SiO_2 content and have total alkali concentrations that are intermediate between syenite and diorite porphyry samples. Monzonitic rocks are quartz normative and have low normative "An" numbers. Samples of diorite porphyry are also quartz normative but have higher overall concentrations of CaO, MgO, and Fe_2O_3. The higher alkali and silica signatures of the monzonite suggest that they may have formed by small degrees of fractional crystallization of dioritic magma. The syenite porphyry has the highest degree of alkali enrichment, but the low silica contents suggest that perhaps they formed by partial melting of evolved crustal rocks.

Table 3. Classification of intrusive rocks in the Hesperus Quadrangle using various chemical schemes.

Geochemical Classification Scheme	Reference for Classification Scheme	Compositional Restrictions	Limits	Rock Name (# of points in field)	Classification Field (# of points in field)
Color Index-%An	(1)	normative	mafic to felsic	syenite porphyry 3) monzonite porphyry (3) diorite porphyry (3)	rhyolite (2), dacite (1) rhyolite (1), dacite (2) dacite (2), andesite (1)
alkalies vs. silica	(1)	none	mafic to felsic	syenite porphyry (3) monzonite porphyry (3) diorite porphyry (3)	alkaline (3) alkaline (3) alkaline (1), subalkaline (2)
Ne-Ol-Q*	(1)	normative	mafic to felsic	syenite porphyry (0) monzonite porphyry (1) diorite porphyry (3)	 subalkaline (1) subalkaline (3)
Ab-An-Or*	(1)	normative	mafic to felsic	syenite porphyry (3) monzonite porphyry (3) diorite porphyry (3)	potassic (3) potassic (3) potassic (3)
K_2O-SiO_2	(2)	none	mafic to felsic	syenite porphyry (3) monzonite porphyry (3) diorite porphyry (3)	all samples plot high-K in the calkalkaline to shoshonitic fields
Ab-An-Or*	(3)	normative	felsic	syenite porphyry (3) monzonite porphyry (3) diorite porphyry (3)	granite (3) granite (3) granodiorite (2), trond hjemite (1)
alkalies vs. silica (TAS)	(4)	none	mafic to felsic	syenite porphyry (3) monzonite porphyry (3) diorite porphyry (3)	alkali syenite (3) alkali syenite (3) alkali syenite (1), alkali syeno-diorite (2)
K_2O-SiO_2	(5)	none	mafic to felsic	syenite porphyry (3) monzonite porphyry (3) diorite porphyry (3)	high-K fields (3) high-K fields (3) high-K fields (3)
alkalies vs. silica (TAS)	(6)	none	mafic to felsic	syenite porphyry (3) monzonite porphyry (3) diorite porphyry (3)	trachyte (3) trachyte (3) trachydacite (2), trachyan desite (1)
K_2O-SiO_2	(7)	none	mafic to felsic	syenite porphyry (3) monzonite porphyry (3) diorite porphyry (3)	subalkaline to alkaline (3) subalkaline to alkaline (3) subalkaline to alkaline (3)

* Normative mineralogy calculated from the major oxide chemical analyses (see Tables 1 and 2)

(1) Irvine and Baragar (1971); (2) Peccerillo and Taylor (1976); (3) Barker (1979); (4) Cox and others (1979); (5) Gill (1981); (6) Le Maitre and others (1989); (7) Rickwood (1989)

MINERAL AND ENERGY RESOURCES

Historic mineral and energy production in the Hesperus quadrangle includes coal, sand, gravel, gold, silver, copper, lead, and zinc. Locations of sand and gravel pits, petroleum test wells, and some of the coal and metal mines are shown on the geologic map. Locations of named coal and metal mines are shown on figure 4. The King Coal mine in Hay Gulch is the only active coal mine in the quadrangle. A small gold operation has recently initiated efforts to construct a small vat-leach operation at the Incas mine in Little Deadwood Gulch near the top of Ohwiler Ridge. One petroleum test well has been drilled in the quadrangle; it was plugged and abandoned. The Fruitland Formation, which is a major coalbed methane-producing formation in adjacent parts of the San Juan Basin, is not present in the Hesperus quadrangle because the formation was removed by erosion long ago. Surficial units containing potentially economic deposits of sand and gravel are mentioned in the section on “Description of Map Units”.

COAL

Over five million tons of coal have been produced from the mines within the Hesperus quadrangle (table 4, figure 4). All coal production in the quadrangle has been from the upper and middle parts of the Menefee Formation. Nearly all historical coal production has come from underground mines. The only currently operating coal mine in the quadrangle is the King Coal mine in Hay Gulch, operated by National King Coal, LLC. Well over half of the entire historic coal production for the quadrangle is from this single mine.

Most coal produced in Hay Gulch has been mined from the Peacock coal bed, which is referred to as the “A” seam by National King Coal, LLC (Trent Peterson, 1999, oral communication). This bed is at the top of the Menefee Formation, immediately below the overlying Cliff House Sandstone. Although published records state that the Burnwell no. 2 mine produced from the Peacock seam (Boreck and Murray, 1979), field investigations indicate this mine’s adits were driven into the middle part of the Menefee Formation, probably into a coal bed referred to as the “B” seam by National King Coal, LLC (Trent Peterson, 2000, oral communication. Mines near Hesperus, such as the Old Hesperus, Hesperus, Monarch, and Ute mines, worked either the Monarch or Hesperus seams in the middle part of the formation. Coal in the Menefee Formation is mostly low-sulfur bituminous coal that ranges from about 12,300 to 13,320 BTUs/pound and 0.5 to 3.0 percent sulfur (Boreck and Murray, 1979).

METALLIC RESOURCES

Eckel (1949) summarized the development of the La Plata mining district, which includes the northern part of the quadrangle. The first report of metal mining in the La Plata Mountains dates back to the mid-1700s when Escalante’s expedition of 1776 found the workings from prior Spanish mining efforts (Bancroft, 1890). Placer gold was discovered along the La Plata River in 1873, and in that same year or in the following one the Comstock vein was found along the river about 1,000 ft north of the quadrangle. In 1874 the few cabins of Parrott City, which later became Mayday, were one of only a handful of scattered settlements in the San Juan basin. Most ranchers had left the area because of problems with the Utes.

Although the gold placers never produced any significant quantities, additional vein discoveries were made during 1875 and hundreds of gold and silver lode claims were filed (Eckel, 1949). At this time the development of the district began in earnest, but by the end of the century it had failed to live up to expectations. Several exciting discoveries, however, were made during the early part of the 20th century. The Neglected mine, located northeast of the quadrangle in the upper reaches of Junction Creek, came into production during 1901. Within the Hesperus quadrangle the Idaho vein was discovered in 1902 and the May Day deposits were found in 1903. Over half of the total production from the district eventually was recovered from the Idaho and May Day mines. The Incas deposit was located in 1909 and quickly yielded $260,000 of gold during the next three years.

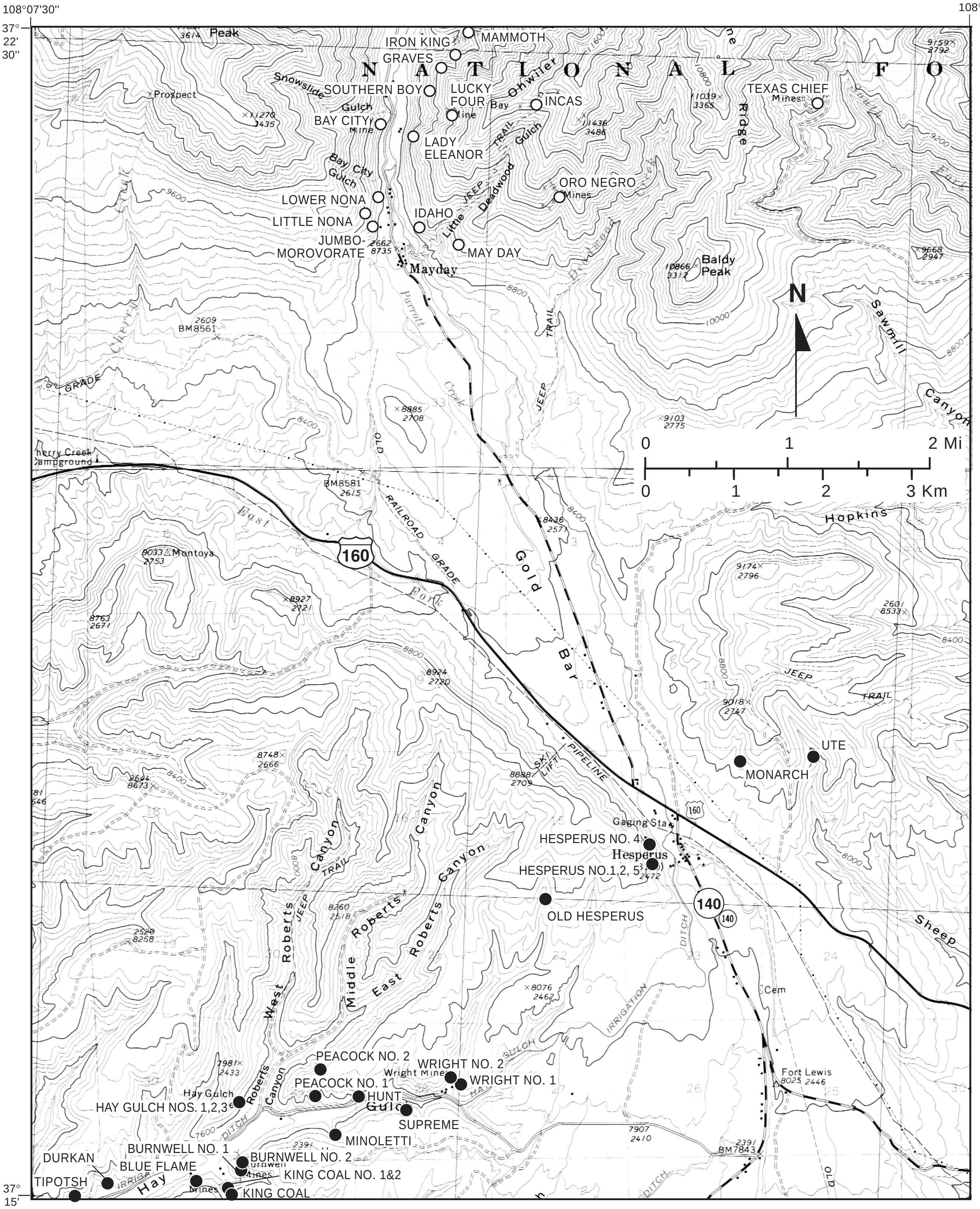

Figure 4. Map showing known mine locations in Hesperus quadrangle. Locations are based on Boreck and Murray (1979), Sulllivan and Jochim (1984), Eckel (1949), Zapp (1949), and Neubert and others (1992), and on field work conducted during this investigation. Solid circle = coal mine, open circle = precious metal mine or prospect. Some mines have been known by more than one name.

Table 4. Coal mine data for Hesperus quadrangle (from Zapp, 1949; Boreck and Murray, 1979; Sullivan and Jochim, 1984; Colorado Division of Minerals and Geology, 2000). Table includes reported production data through 1999, name and thickness of the mined bed, and dates of operation. Refer to figure 3 for mine locations.

MINE NAME	BED NAME & THICKNESS (feet)	DATES OF OPERATION	PRODUCTION (tons)	NOTES
Blue Flame	Peacock; 6.0	1948–1971	30,797	
Burnwell #1	Peacock; 6.5	1958–1970	39,947	Gas explosion 1966
Burnwell #2	B; 6.5	1949–1967	47,270	Gas reported
Coal King #1 & 2	Peacock; 6.3-6.5	1938–1965	41,793	
Durkan	Peacock; 5.0-6.5	1935–1951	7,203	
Hay Gulch #1, 2, & 3	Peacock; 6.5	1933–1964	59,503	
Hesperus #1; Klondyke	Monarch; 5.0-9.0	1937–1939	7,439	
Hesperus #2	Monarch; 9.1	1945–1953	11,165	Closed due to fire
Hesperus #4	Hesperus; 9.1	1960–1971	26,358	
Hesperus #5	Hesperus	1971–1972	5,824	Includes underground & strip production
Hunt; Gadberry	Peacock; 5.0-5.6	1925–1946	13,479	
King Coal	A or Peacock; 6.0-7.0	1939-present	3,563,656	Reported gassy in 1956; Partly on Kline quad
Minoletti;Rasmussen; Dufur; Sundance; Sundance strip	Peacock; 5.5-7.0	1941–1961	56,921	
Monarch; Hesperus #3	Monarch; 8.5	1944–1958	20,118	
New Fort Lewis[1]	Peacock; 9.0	1943–1949	1,395	
New La Plata[2]	Monarch;5.9	1950–1954	1,562	
Old Hesperus	Monarch; 9.1	1892–1922	895,067	
Peacock #1 & 2; La Plata #1?	Peacock; 5.0-6.0	1922–1981	76,052	
Shalako[3]	4.0-6.0			
Supreme Peacock;	5.3-5.9	1937–1947	21,076	
Tipotsh	Peacock or Big Vein; 5.5-6.0	1923–1953	22,096	Partly on Kline quad
Ute	Monarch; 4.5-5.0	1892–1906	146,013	
Wright #1	Peacock; 5.0	1943–1961	10,605	
Wright #2	Peacock; 5.9	1941–1955	34,024	
Wrights[4]	Peacock; 2.1	1923	210	
Total known production:			**5,135,966 tons**	

[1] exact location uncertain; reportedly in SE1/4 SE1/4 of section 29, T. 35 N., R. 11 W.; not plotted on Figure 3

[2] exact location uncertain; reportedly in SW1/4 SE1/4 SE1/4 section 11, T. 35 N., R. 11 W.; not plotted on Figure 3

[3] exact location uncertain; reportedly in section 29, T. 35 N., R. 11 W.; not plotted on Figure 3

[4] exact location uncertain reportedly in section 28, T. 35 N., R. 11 W.; not plotted on Figure 3

Approximate locations of the named metal mines in the quadrangle are shown on Figure 4. They include the May Day, Idaho, Incas, Jumbo-Morovoratz, Little Nona, Lower Nona, Bay City, Texas Chief, Lucky Four, Oro Negro, Lady Eleanora, Southern Boy, Graves, Iron King, and Mammoth mines. Eckel (1949) and Neubert and others (1992) have described these mines. Most of the following descriptions are based on these two references.

The May Day mine and adjoining Idaho mine are on the east side of the La Plata River near the mouth of Little Deadwood Gulch. Recorded production for the two mines is about 133,000 oz of gold, 1,140,000 oz of silver, 24,000 lb of lead, 8,000 lb of zinc, and 1,500 lb of copper (Neubert and others, 1992). Ore occurs as replacement deposits in the Pony Express Limestone Member of the Wanakah Formation and in six north-trending veins hosted by sedimentary rocks in the Dolores, Entrada, Wanakah, Junction Creek, and Morrison formations and in sills and dikes of diorite porphyry. The veins have a vertical extent that exceeds 1,200 ft. They are wide and well developed in hard and brittle sandstone and limestone beds, and are narrow and poorly developed in less competent rocks such as shale, siltstone, and mudstone. Most replacement deposits are within about 50 ft of the veins.

Eckel (1949) believed that movement on the May Day and Idaho faults predated mineralization. These faults are generally barren, contain gouge, and were thought to have served as hydrologic dams for the rising mineral-bearing solutions (Eckel, 1949). The mineralized rock, which contains quartz, pyrite, barite, telluride, native gold, and limited base-metal sulfides, formed in adjacent open fractures. Neubert and others (1992) assayed samples of the May Day vein and Junction Creek Sandstone wallrock that were provided by the mine owners. The vein contained 0.772 ounces/ton of gold, 11.6 oz/ton silver, and 380 parts per million (ppm) tellurium. The sandstone wallrock assayed at 0.07 oz/ton of gold.

After its original discovery in 1909, the Incas mine experienced considerable activity for the following three years, but it has been worked only intermittently since then. During the summer of 1999 efforts were underway to construct a small vat-leach operation to process dump rock (Bob Hill, 1999, oral communication). Recorded production amounts to about 12,000 oz of gold, 15,000 oz of silver, and minor amounts of copper and lead.

Mineralized rock occurs in both veins and replacement deposits at the Incas mine. Most of the replacement deposits are in the Pony Express Limestone, but some ore has also been produced from an altered sandstone bed in the Wanakah Formation immediately above the limestone. Ore minerals include native gold and tellurides in a gangue of quartz and ankerite. Of eleven samples collected by Neubert and others (1992), five had more than 0.03 oz/ton of 1,000 parts per billion (ppb) of gold. Except for limonite staining, none of the samples contained visible metallic minerals.

Other metal mines within the Hesperus quadrangle have been much less productive than the May Day-Idaho and Incas Mines. The Jumbo-Morovoratz and Little Nona mines are on the opposite side of the La Plata River from the May Day-Idaho Mines (Figure 3). Neubert and others (1992) reported the Jumbo-Morovoratz and Little Nona mines produced about 160 oz of gold, 40,000 ounces of silver, 1,000 lb of copper, and 7,500 lb of lead. These mines are in the western part of the May Day-Idaho fault system. Southward dipping sedimentary formations in this area, including the Entrada, Wanakah, and Junction Creek, are cut by dikes and sills of diorite porphyry. Several minor faults that trend generally northeastward were exposed in the workings. These faults have only a few feet of displacement, and some are mineralized. The Jumbo vein reportedly contained gouge, breccia, quartz, barite, cerargyrite, and cerrusite (Eckel, 1949; Neubert and others, 1992). Silver concentrations of 5.78 oz/ton in a dump sample and 5.44 oz/ton for a select sample of vein material were reported by Neubert and others (1992).

The Bay City Mine is on the west side of the La Plata River near the mouth of drainage called Snowslide Gulch on our base maps. Eckel (1949) referred to this drainage as the Bay City Gulch. This mine was discovered in 1876, early in the history of the district, and it reportedly yielded rich gold ore during initial operations. These early ore samples contained about $800 of gold per ton, which, at the price of gold at that time, translates into very high gold concentrations. Recorded production is about 100 oz of gold, 200 ounces of silver, and 4,000 lb of copper. The ore is hosted in a limy bed locally called the Bay City limestone that lies at the base of the Dolores Formation. Near the portal of the adit the bed is an approximately 10-ft-thick limestone locally altered to marble. Laterally it grades to a limestone conglomerate that is typical of the lower Dolores or to sandy mudstone (Eckel, 1949). The replaced zone is 2 to 3 ft thick and contains magnetite, specular hematite, pyrite, chalcopyrite, galena, epidote, quartz, barite, calcite, and probably native gold. The sedimentary rocks are cut by irregular diorite porphyry dikes and sills. Of eleven ore samples collected by Neubert and others (1992) three contained over 1,000 ppb (0.03 oz/ton) of gold, one of which ran 0.348 oz/ton.

The Texas Chief Mine is on a hillslope west of the South Fork of Lightner Creek. It is the only mine in the northeast corner of the quadrangle. The workings are in red beds of the Dolores and Cutler Formations that are intruded by irregular sills and dikes of diorite porphyry. The workings are adjacent to one of the larger intrusive stocks in the quadrangle. Although only one vein is shown on our map, Eckel (1949) reported there were at least ten thin, discontinuous veins at this mine. Vein minerals include quartz, siderite, manganocalcite, pyrite, sphalerite, galena, chalcopyrite, and pyargyrite. Production is reported only for six years between 1917 and 1928 (Eckel, 1949). During that time about 2,400 oz of silver, 10 ounces of gold, and 1,000 pounds of copper were mined. Neubert and others (1992) collected 14 samples from this mine for analysis. Seven contained over 100 ppm (3 oz/ton) of silver; one sample from a fault in the main adit carried 24.42 oz/ton of silver. The highest gold concentration was 1,082 ppb (0.03 oz/ton). Three samples had over 1 percent lead; one contained 1.81 percent lead.

The Lucky Four group of claims is on the west end of Ohwiler Ridge across the river from and well above the Bay City Mine. It has also been called the Former Bay Mine and is labeled as such on the Hesperus 7.5-minute topographic base map by the USGS. Little is known about the production history of the Lucky Four Mine. During the two years (1907 and 1914) that production was reported, the mine yielded about 800 oz of gold, 6,800 oz of silver, 10,000 pounds of copper, and 5,000 lb of lead. Most of the ore probably came from replacement deposits in the Pony Express Limestone Member and from veins in the Entrada Sandstone. Most of the workings were closed before Eckel (1949) studied the mine. Neubert and others (1992) collected five samples from the accessible veins, one of which is hosted in gently dipping red beds in the Dolores Formation and strikes on average N15°E and dips 75° southeast. The highest gold concentration was 2,860 ppb (0.08 oz/ton) and the highest base metal concentration was 1.71 percent lead. This vein contained clay, barite, quartz, galena, sphalerite, and pyrite and is locally brecciated.

The Oro Negro group of claims is in a ravine between Ohwiler Ridge and Deadwood Creek that was locally known as Oro Negro Gulch. No production has been reported for these workings, which Eckel (1949) thought were driven into the May Day-Idaho fault system. Our mapping suggests the structure is part of the Ohwiler Ridge Fault. The country rock in this area is locally brecciated and highly silicified. The workings were not accessible when Eckel (1949) visited them. Neubert and others (1992) sampled the dumps and exposed breccia zones. The highest gold value found in ten samples was 1,190 ppb (0.04 oz/ton).

The Lady Eleanora Mine, also known as the Little La Plata, is on the east side of the La Plata River between Mayday and Burnt Timber Gulch. Three veins were worked, the N 25° E-trending Little La Plata vein, and two north-striking veins thought by the mine operators to be extensions of the Idaho and Valley View veins (Eckel, 1949). These veins occurred chiefly in the Dolores Formation and, to a lesser degree, in a porphyry dike. Quartz, siderite, pyrite, arsenopyprite, chalcopyrite, tetrahedrite, galena, and sphalerite were found in the veins. Clastic sedimentary beds exposed in the workings were locally silicified, and limestone conglomerate beds were metamorphosed. Where these metamorphosed beds were oxidized, they contained free gold. Eckel (1949) reported that production from this mine amounted to about 36 oz of gold, 533 oz of silver, 110 lb of copper, and 930 pounds of lead during seven years between 1906 and 1923.

The Southern Boy mine is on the east bank of the La Plata River south of the mouth of Burnt Timber Gulch. This mine and the adjacent Southern Girl claim were discovered in the late 1880s and early 1890s. Although there is no record of early production, Petre (1898) noted their importance because of some very rich sylvanite ore found near the surface. Eckel (1949) described an unpublished production report from 1901 that stated the Southern Boy Mine produced 19 tons of ore which contained 117 ozs of gold and 142 oz of silver. Total known production for the mine is 170 oz of gold, 380 ounces of silver, 25 pounds of copper, and 407 lb of lead (Eckel, 1949). The mine was developed in a north- to north-north-west striking vein that dips steeply east. It consisted of a 1 to 3 ft silicified fracture zone in porphyry with quartz, ankerite, barite, pyrite, galena, and chalcopyrite.

On the east side of the La Plata River, northeast of and above the Southern Boy mine, is the Graves mine. This mine worked two northeast-trending veins but never produced much ore. Vein minerals include quartz, pyrite, chalcopyrite, galena, tetrahedrite, ankerite, calcite, barite, and a manganese oxide. Where oxidized, the ore contained free gold. A sample from a thin mineralized vein above a caved adit carried 1,050 ppb (0.03 oz/ton) gold (Neubert and others, 1992).

The Iron King Mine lies about one-half mile above the mouth of Burnt Timber Creek. It worked a northeast-striking shear zone mainly in silicified clastic beds of the Cutler Formation that contained breccia, quartz, pyrite, barite, ankerite, galena, and sphalerite. No production figures are available for this small operation. A second small prospect, the Mammoth Mine, occurs along Burnt Timber Creek a short distance above the Iron King mine. It was being actively worked in 1896, but does not have any known production. It reported developed a replaced sandstone bed in the Cutler Formation that contained gold-bearing layers and lenses of pyrite.

PETROLEUM RESOURCES

A single petroleum test well has been drilled in the Hesperus quadrangle (unpublished file information held by the Colorado Oil and Gas Conservation Commission; Petroleum Information/Dwights LLC, 1998). The Great Western Drilling-Hondo-Pan American Fort Lewis no. 1–33 well was drilled to a total depth of 3,095 ft near the southern edge of the quadrangle in 1956. The target formation was the Dakota Sandstone, but the well was a dry hole that was plugged and abandoned. A well drilled in 1990 about 2,200 ft west of the southwest corner of the quadrangle, the United Company BFL State no. 1, produced eight barrels of oil from the Dakota Sandstone during a 24-hour pump test, but it was never completed for production.

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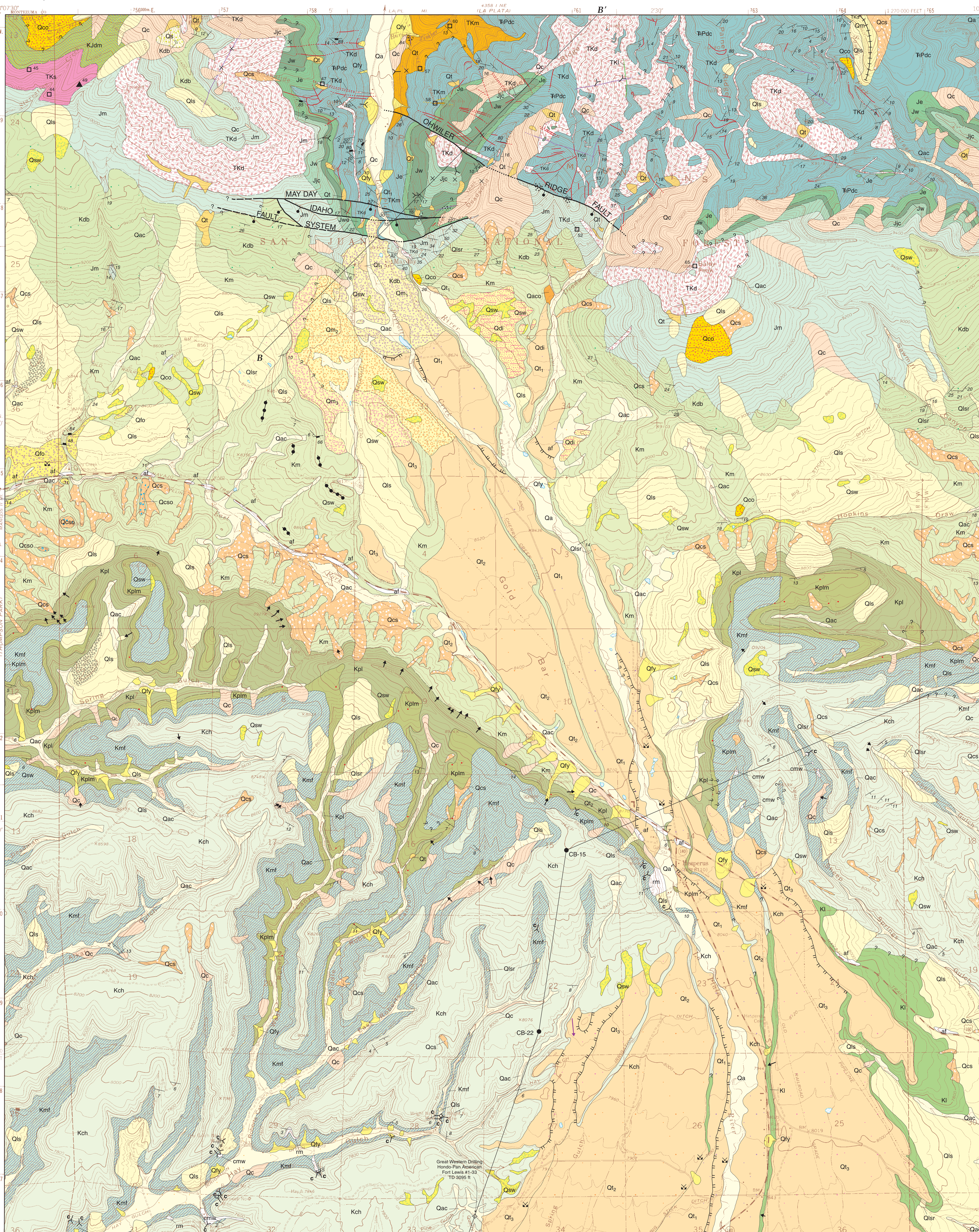


Base from U.S. Geological Survey, 1963
Polyconic projection, 1927 North American datum
10,000-foot grid based on Colorado coordinate system, central zone

UTM GRID AND 1963 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:24,000

CONTOUR INTERVAL 40 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

QUADRANGLE LOCATION

Geology mapped in 1999
Digital map prepared by Cheryl Brchan

CONDENSED DESCRIPTION OF MAP UNITS

Expanded descriptions can be found in accompanying booklet.

SURFICIAL DEPOSITS

HUMAN-MADE DEPOSITS

af **Artificial fill (latest Holocene)**—Fill and waste rock placed during construction of roads and dams

cmw **Coal mine waste (latest Holocene)**—Rock fragments and coal refuse placed in dump piles and in operational areas near coal mines

rm **Reclaimed mine (latest Holocene)**—Rock fragments and surficial deposits that have been reclaimed at several permitted or abandoned coal mines

ALLUVIAL DEPOSITS—Sediments deposited in stream channels, flood plains, glacial outwash terraces, and sheetwash areas

Qa **Stream-channel, flood-plain, and low terrace deposits (Holocene)**—Poorly sorted, clast-supported, unconsolidated, silty, sandy, and occasionally bouldery pebble and cobble gravel in a sandy or silty matrix

Qsw **Sheetwash deposits (Holocene and late Pleistocene)**—Pebbly, silty sand, sandy or clayey silt, and sandy, silty clay in valleys of ephemeral and intermittent streams and in basins

Qt_1 **Terrace alluvium one (late Pleistocene)**—Chiefly stream alluvium that underlies several terrace surfaces along the La Plata River; they sharply converge with the La Plata River in a downstream direction. Height above river near south edge of quadrangle is only 10–35 ft. Near Mayday, however, these terraces are up to 100 ft above the river, and they physically grade to correlative moraines (Qm_1). Mostly poorly sorted, clast-supported, locally bouldery, pebble and cobble gravel in a silty or sandy matrix. May include fine-grained overbank or overlying sheetwash deposits

Qt_2 **Terrace alluvium two (late? and late middle Pleistocene)**—Mostly stream alluvium that underlies at least two terrace surfaces that converge downstream with the La Plata River. Deposits are similar to terrace alluvium one (Qt_1). At the north end of Gold Bar, Qt_2 terraces are about 150–160 ft above the river, whereas near the southern edge of the quadrangle they are only about 80 ft above it. One Qt_2 terrace physically grades to a correlative moraine (Qm_2) at the northern end of Gold Bar

Qt_3 **Terrace alluvium three (middle Pleistocene)**—Chiefly stream alluvium similar to terrace alluvium one (Qt_1) that underlies several terrace surfaces that sharply converge with the La Plata River in a downstream direction. In the southern end of the map area the terraces are about 110–130 ft above the river. Between Hesperus and Mayday one Qt_3 terrace is 320–350 ft above the river, and it physically grades to a correlative moraine (Qm_3)

COLLUVIAL DEPOSITS—Sediments deposited on valley sides, valley floors, and hillslopes that were mobilized, transported, and deposited primarily by gravity

Qlsr **Recent landslide deposits (latest Holocene)**—Includes several recently active landslides with fresh morphological features. Heterogeneous deposits consisting of unsorted, unstratified rock fragments, clay, silt, sand, and sometimes rounded pebbles and cobbles. Soil slips (see explanation of map symbols) are a type of recent landslide, but are too small to be shown as a map unit at a scale of 1:24,000

Qt **Talus (Holocene and late Pleistocene)**—Angular, cobbly, and bouldery rubble on moderate to steep slopes that was derived from prominent outcrops of well indurated bedrock and transported downslope primarily by gravity during rockfalls, rockslides, or rock topples. Locally includes small areas of felsenmeer and rock-glacier deposits

Qc **Colluvium (Holocene and late Pleistocene)**—Ranges from unsorted, clast-supported, pebble to boulder gravel in a sandy or silty matrix to matrix-supported gravelly sand or clayey silt. Deposits are usually coarser grained in upper reaches and finer grained in distal areas. Locally includes small areas of felsenmeer

Qls **Landslide deposits (Holocene and Pleistocene)**—Similar in texture to recent landslide deposits (Qlsr). Range from active, slowly creeping landslides to long-inactive, middle or perhaps even early Pleistocene landslides. Landslides on Paine Ridge may include solifluction deposits

Qco **Older colluvium (Pleistocene)**—Texturally similar to colluvium (Qc), but found on drainage divides, ridge lines, and dissected hillslopes. May include older landslide deposits. Generally not subject to significant future colluviation

ALLUVIAL AND COLLUVIAL DEPOSITS—Sediments in fans, stream channels, flood plains, and adjacent hillslopes along tributary valleys

Qfy **Younger fan deposits (Holocene)**—Sediments deposited by hyperconcentrated flow, debris flow, alluviation, and sheetwash. Range from poorly sorted, clast-supported, pebble, cobble, and boulder gravel in a clayey silt or sand matrix to matrix-supported, gravelly, clayey silt. May be bouldery, particularly in the upper reaches of some fans. Deposits tend to be finer grained in the distal ends of some fans

Qac **Alluvium and colluvium, undivided (Holocene and late Pleistocene)**—Stream-channel, low-terrace, and flood-plain deposits along tributary valley floors. May be interfingered with colluvium and sheetwash (Qcs) along valley sides. Ranges from poorly to well sorted, stratified, pebbly sand and sandy gravel interbedded with sand to poorly sorted, unstratified or poorly stratified clayey, silty sand, bouldery sand, and sandy silt

Qcs **Colluvium and sheetwash deposits, undivided (Holocene and late Pleistocene?)**—Composed of colluvium (Qc) on steeper slopes and sheetwash deposits (Qsw) on flatter slopes. This unit is mapped where contacts between the two types of deposits are very gradational and difficult to locate

Qcso **Older colluvium and sheetwash deposits, undivided (Pleistocene)**—Deposits texturally and depositionally similar to colluvium and sheetwash (Qcs) that occur on drainage divides and hilltops. Generally not subject to future deposition

Qaco **Older alluvium and colluvium, undivided (Pleistocene)**—Includes a single deposit on the west side of Deadwood Creek about 1 mile above the confluence with the La Plata River. Deposits are similar to alluvium and colluvium, undivided (Qac). Remnant is about 20–40 ft above the creek

Qdi **Diamicton (late? Pleistocene)**—Heterogeneous deposits of poorly sorted, angular to subround pebbles, cobbles, and rare boulders in a clayey, sandy, and silty matrix found southeast of Mayday. Origin uncertain. May be older landslide deposits, till, or colluvium and sheet-wash deposits.

Qfo **Older fan deposits (late or middle Pleistocene)**—Remnants of a long-inactive fan on Cherry Creek near the now abandoned Cherry Creek campground. Deposits are similar to younger fan deposits (Qf)

GLACIAL DEPOSITS—Gravel, sand, silt, and clay deposited by ice or adjacent to ice in moraines

Qm_1 **Younger moraine deposits (late Pleistocene)**—Includes till and other ice-margin deposits west of the La Plata River. Mostly a heterogeneous, poorly sorted, matrix-supported unit consisting of cobbles, pebbles, and boulders in a sandy, silty, or clayey matrix. Terraces associated with terrace alluvium one (Qt_1) are graded to younger moraine deposits

Qm_2 **Intermediate moraine deposits (late? middle Pleistocene)**—Till and other ice-margin deposits west of the La Plata River that are sedimentologically similar to younger moraine deposits (Qm_1). Terraces of terrace alluvium two (Qt_2) are graded to intermediate moraine deposits

Qm_3 **Older moraine deposits (middle Pleistocene)**—Till and other ice-margin deposits west of the La Plata River that are sedimentologically similar to younger moraine deposits (Qm_1). Terraces of terrace alluvium three (Qt_3) are graded to older moraine deposits

Qm **Undifferentiated moraine deposits (late or middle? Pleistocene)**—Includes a single, very poorly exposed deposit in South Lightner Creek near the northeast corner of the quadrangle. Landform is arcuate, steep-sided, and parallel to the creek. Deposit is inferred to be moraine deposits based on landform. Probably is sedimentologically similar to younger moraine deposits (Qm_1). Age relationship with moraine deposits in the La Plata River valley is uncertain

PERIGLACIAL DEPOSITS—Sediments deposited in cold environments

Qs **Solifluction deposits (Holocene and late Pleistocene)**—Thin deposits resulting from the slow, downslope flowage of water-saturated materials, probably over frozen ground. Consists of angular to subangular boulders, cobbles, and pebbles in a sand or silt matrix. Deposits occur on southwest end of Parrott Peak

UNDIFFERENTIATED DEPOSITS

Q **Undifferentiated surficial deposits (Quaternary)**—Shown only on cross section

BEDROCK

IGNEOUS ROCKS

TKs **Syenite porphyry (Upper Cretaceous or Paleocene)**—Light-brown to medium-gray syenite porphyry in stock exposed west of Parrott Peak. Weathers reddish brown to light tan. Has pronounced hiatal-porphyritic texture. About 10 to 30 percent of the rock is composed of phenocrysts and microphenocrysts of plagioclase, hornblende recrystallized to aegerine-augite, apatite, sphene, and opaque minerals. Matrix is very fine grained and consists mostly of feldspar that is altered and recystallized to sericite, epidote, clay, and calcite

TKl **Lamprophyre (Upper Cretaceous or Paleocene)**—Includes a single dike in upper Deadwood Creek on the southeast side of Ohwiler Ridge. Consists of dark-green to greenish-black porphyritic rock with phenocrysts of hornblende 3 to 5 mm long set in a fine-grained groundmass composed chiefly of hornblende and plagioclase. Phenocrysts comprise about 10 to 30 percent of the rock

TKm **Monzonite porphyry (Upper Cretaceous or Paleocene)**—Light-tan to light-gray monzonite porphyry exposed in a stock at the mouth of Burnt Timber Creek and in nearby dikes and sills. Weathers brown or reddish brown. Contains 20 to 60 percent phenocrysts and microphenocrysts (0.5 to 6 mm in size) of feldspar, augite, hornblende, apatite, sphene, and opaque minerals that are set in a very fine-grained to fine-grained, feathery groundmass of feldspar. Outcrops are frequently highly altered. Two samples of monzonite porphyry were dated using $^{40}Ar/^{39}Ar$ single-crystal laser total fusion methods. A sample from a dike (5) yielded a weighted mean age of 70.36 ± 0.86 Ma based on analyses of seven hornblende crystals. A sample from a stock (60) had a weighted mean age of 75.19 ± 0.66 Ma using analyses of ten hornblende crystals.

TKd **Diorite porphyry (Upper Cretaceous or Paleocene)**—Dikes, sills, and stocks of light-gray diorite porphyry. Weathers medium gray or white to brown. Consists of 10 to 65 percent phenocrysts (1 to 10 mm in size) of subhedral to euhedral plagioclase, hornblende, opaque minerals, apatite, and sphene

SEDIMENTARY ROCKS

Kl **Lewis Shale (Upper Cretaceous)**—Dark-gray, fissile shale containing thin sandstone beds at top and gray, rusty-weathering concretionary limestone in the lower part

Mesaverde Group (Upper Cretaceous)—Consists of three formations in the Hesperus quadrangle, which, in descending order, are the Cliff House Sandstone, Menefee Formation, and Point Lookout Sandstone

Kch **Cliff House Sandstone**—Interbedded sequence of thin beds of moderately hard, commonly silty, yellowish-orange to white, very fine- to fine-grained calcareous sandstone and less indurated light-gray mudstone and silty shale

Kmf **Menefee Formation**—Interbedded, light-gray, brown, and orange-brown sandstone and siltstone, gray, brown, and black carbonaceous shale, and coal. Sandstone beds are commonly lenticular. Locally includes burnt rock and clinker resulting from burning of coal beds within the formation

Kplu **Point Lookout Sandstone, undivided**—Shown only on cross section. Consists of two lithostratigraphic members, a lower part and an overlying massive part

Kplm **Massive part of Point Lookout Sandstone**—Thick beds of light-gray to yellowish-gray or brown quartzose sandstone with very minor interbeds of dark-gray shale. Sandstone is fine to medium grained, cross laminated, well sorted, and cemented with calcite

Kpl **Lower part of Point Lookout Sandstone**—Sequence of interbedded thin sandstone and shale beds that are gradational between the massive part of the Point Lookout Sandstone and the Mancos Shale. Basal contact arbitrarily placed at the base of the lowest 1-ft-thick sandstone bed or where the strata contain more than 50 percent shale in a 6-ft-thick stratigraphic interval

Km **Mancos Shale (Upper Cretaceous)**—Dark-gray to black shale and silty shale, dark-gray to blue-gray argillaceous limestone, and calcarenite. Includes numerous thin beds of bentonite, especially in the lower part of the formation, and thin, sometimes argillaceous sandstone beds in the upper part immediately below contact with lower part of the Point Lookout Sandstone

Kdb **Dakota Sandstone (Upper Cretaceous) and Burro Canyon Formation (Lower Cretaceous), undivided**—Dakota Sandstone composed of light- to medium-gray, light- to medium-brown, and yellowish-brown conglomeratic sandstone, fine- to coarse-grained sandstone, and conglomerate interbedded with dark- to medium-gray siltstone, carbonaceous shale, and thin coal beds. Burro Canyon Formation consists of sandstone, chert-pebble conglomerate and grayish-green, non-carbonaceous claystone

Jm **Morrison Formation (Upper Jurassic)**—Consists of an upper Brushy Basin Member and a lower Salt Wash Member. Brushy Basin Member is chiefly greenish-gray, occasionally reddish-brown, bentonitic mudstone and claystone containing thin beds of very fine-grained sandstone and minor conglomeratic sandstone. Salt Wash Member is mainly silicified, light-gray to white, fine- to medium-grained, lenticular sandstone inter-bedded with thin beds of greenish-gray mudstone

KJdm **Dakota Sandstone, Burro Canyon Formation, and Morrison Formation, undivided (Upper and Lower Cretaceous and Upper Jurassic)**—Shown only in northwest part of quadrangle where poor exposures limit recognition of contacts

Jjc **Junction Creek Sandstone (Middle Jurassic)**—Light-gray to tan, highly crossbedded to massive, fine- to coarse-grained sandstone. Correlative with the Bluff Sandstone in the Four Corners Region and southeastern Utah

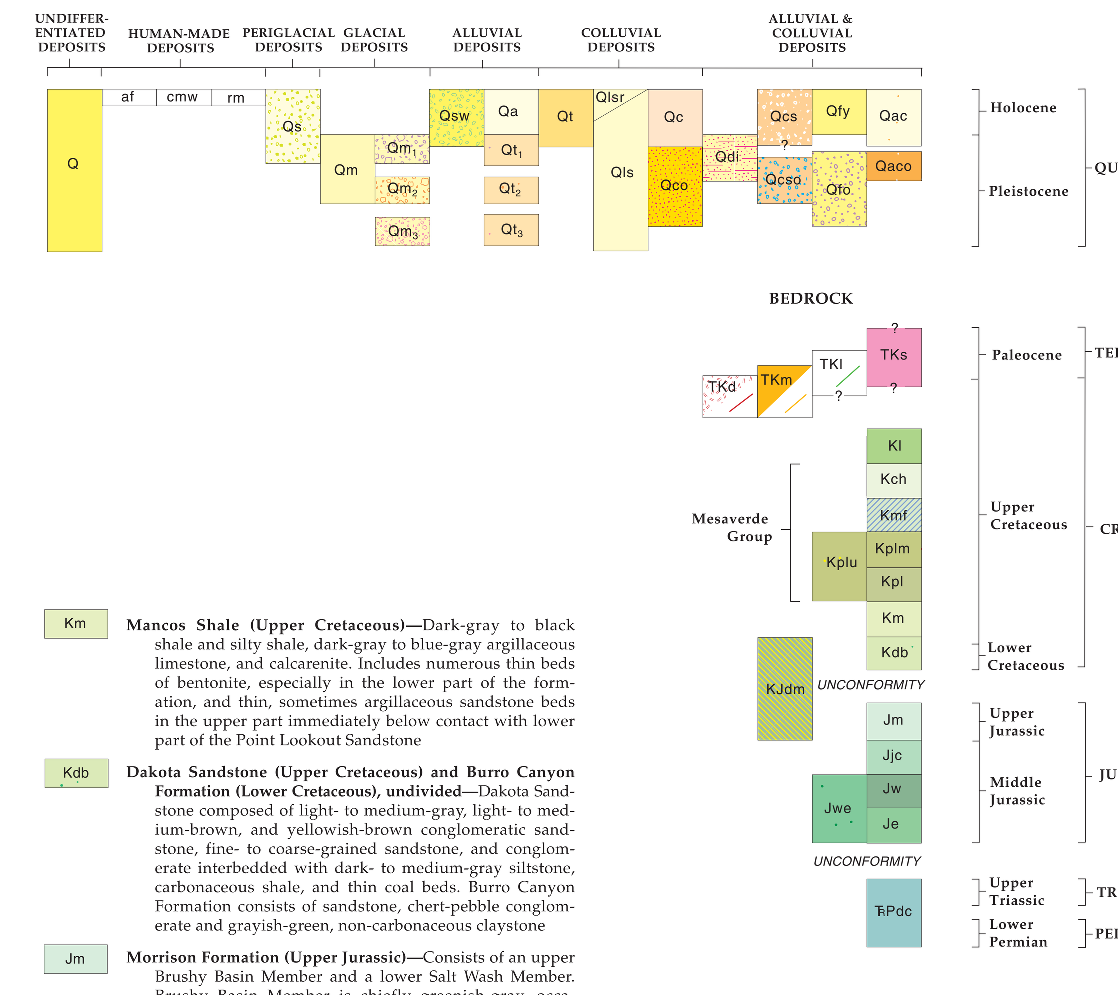
Jw **Wanakah Formation (Middle Jurassic)**—Consists of an upper member composed mainly of white to tan, reddish-orange, and reddish-brown, very fine- to fine-grained sandstone and reddish-brown to greenish-gray mudstone; and a lower member, the Pony Express Limestone Member, consisting of medium- to dark-gray, very thin-bedded to laminated, micritic, oolitic, and algal limestone. Correlative with the Summerville Formation in the Four Corners region. Pony Express Limestone Member correlates with the Todilto Limestone in New Mexico

Je **Entrada Sandstone (Middle Jurassic)** —Light-gray to white, sometimes orangish-gray, fine- to coarse-grained, highly crossbedded sandstone

Jwe **Wanakah Formation and Entrada Sandstone, undivided (Middle Jurassic)**—Mapped only on west side of La Plata River near Mayday where poor exposures limit recognition of the contact between the two formations

ⱤPdc **Dolores and Cutler Formations, undivided (Upper Triassic and Lower Permian)**—Dolores Formation includes dark-reddish-brown to purplish-red shale and siltstone and light-brown, gray, and reddish-brown lenticular sandstone and limestone-pebble conglomerate containing rare thin limestone beds. Limestone-pebble conglomerate beds contain rare crocodilian teeth and bone fragments. Dolores Formation is correlative with the Chinle Group in adjacent areas. Cutler Formation contains medium- to dark-reddish-brown, medium-gray, and medium- to dark-brown sandstone, arkosic sandstone, and arkosic conglomerate and reddish-brown to purplish-brown shale and siltstone containing occasional limestone-pebble conglomerate beds and rare, thin limestone beds

CORRELATION OF MAP UNITS



SYMBOLS

Contact—Dashed where approximately located; queried where uncertain

Fault—Dashed where approximately located; dotted where concealed; bar and ball on downthrown side

Fault breccia zone

Igneous dike—Dotted where approximately located or concealed; diorite porphyry dikes shown in red; monzonite porphyry dikes shown in orange; lamprophyre dike shown in green

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

Strike and dip of dominant joint set—Angle of dip shown in degrees

Soil slip—Small, thin recent landslides on steep hillslopes; most appear to be small debris avalanches involving colluvium, residuum, and sheetwash on slopes underlain by Mancos Shale, Point Lookout Sandstone, Menefee Formation, and Cliff House Sandstone; length of arrow approximately equals the length of the slip path

Toreva block—Large, relatively intact block of dislocated bedrock within a large landslide; other toreva blocks may exist in the quadrangle

Moraine crest

Linear valley in Mancos Shale—Probably an incipient landslide scarp developed in Mancos Shale or a sackung feature related to lateral spreading of a bedrock ridge

Tributary channel—Location of tributary channel in older terrace alluvium (Qt_3); clasts are mostly locally derived sandstone and siltstone

Terrace scarp or riser

Mineralized vein—Dotted where concealed by surficial deposits or heavy vegetative cover

Coal-mine adit—Only those coal-mine adits observed in the field are shown; may represent more than one adit where they are in close proximity; refer to the original mine maps held by the Colorado Division of Minerals and Geology, Sullivan and Joachim (1984), and Zapp (1949) for locations of other coal mine adits; all observed adits have either collapsed shut or been safeguarded

Hard-rock adit—Includes only those hard-rock adits that were noted in the field and which were not depicted on maps by Eckel (1949)

Hard-rock prospect pit—Includes only those hard-rock prospect pits that were noted in the field and which were not depicted on maps by Eckel (1949)

Sand or gravel pit

Great Western Drilling Hondo-Pan American Fort Lewis #1-33 TD 3095 ft **Plugged and abandoned petroleum test well**—Operator, well name, and total depth given; information based on records of Colorado Oil and Gas Conservation Commission; location not confirmed by field inspection

CB-15 **Coal exploration drill or core hole, with identification number; only those used on cross section are shown**

44 **Location and identification number of sample submitted for geochemical analysis**

49 **Location and identification number of sample submitted for $^{40}Ar/^{39}Ar$ geochronologic dating and geochemical analysis**

A——A′ **Alignment of cross section**

ACKNOWLEDGMENTS

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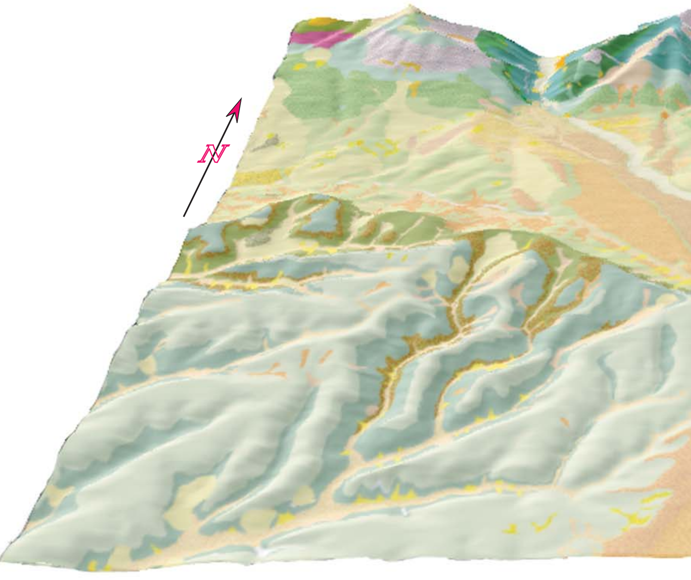
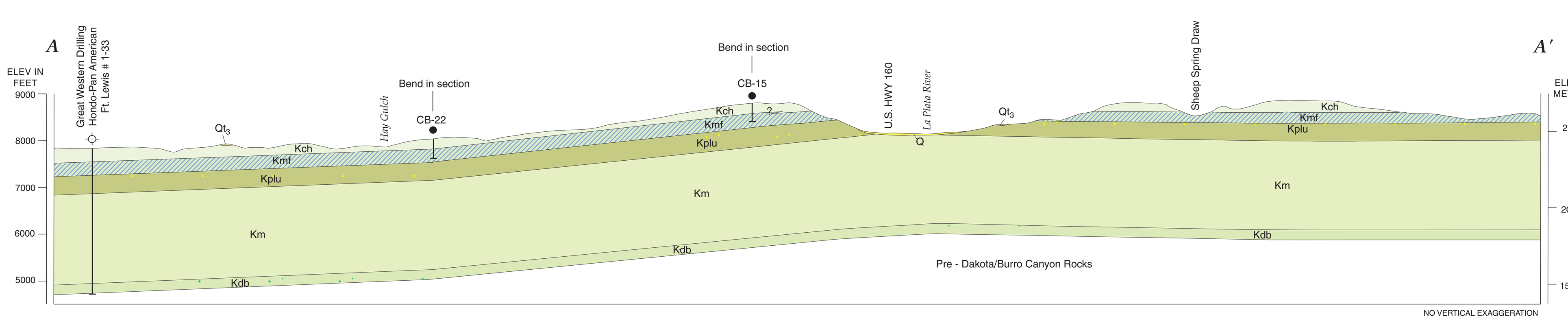
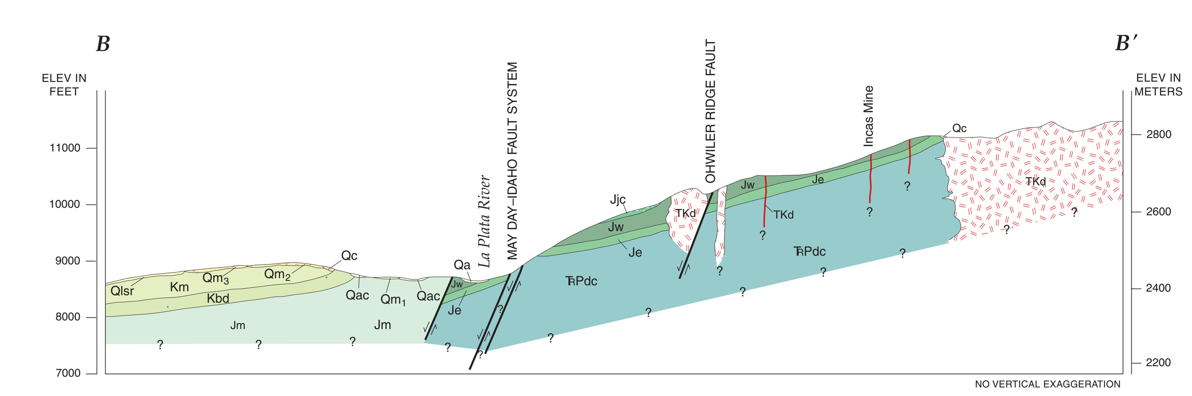
SHADED RELIEF MAP OF THE HESPERUS QUADRANGLE WITH GEOLOGY OVERLAY; OBLIQUE VIEW LOOKING NORTH







GEOLOGIC MAP OF THE HESPERUS QUADRANGLE, LA PLATA AND MONTEZUMA COUNTIES, COLORADO

By Robert M. Kirkham, David A. Gonzales, Christopher Poitras, Kendra Remley, and Douglas Allen

2000