OPEN-FILE REPORT 06-6

Geologic Map of the Palmer Lake Quadrangle, El Paso County, Colorado

Bill Ritter Jr., Governor
State of Colorado

COLORADO
DEPARTMENT OF
NATURAL
RESOURCES

Harris D. Sherman, Executive Director
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Vincent Matthews
State Geologist and Division Director
Colorado Geological Survey

by
John W. Keller[1], Matthew L. Morgan[1], Jon P. Thorson[2],
Neil R. Lindsay[3], and Peter E. Barkmann[1]

[1] Colorado Geological Survey, Denver, CO
[2] Consulting Geologist, Parker, CO
[3] Colorado Geological Survey, Alamosa, CO

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Description of Map Units, Structural Geology, Mineral Resources, Geologic Hazards, and Water Resources

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John W. Keller[1], Matthew L. Morgan[1], Jon P. Thorson[2],
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[1] Colorado Geological Survey, Denver, CO
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This mapping project was funded jointly by the Colorado Geological Survey and the U.S. Geological Survey through the National Geologic Mapping Program under STATEMAP Agreement No. 05HQAG0064.

Bill Ritter, Governor, State of Colorado
Harris Sherman, Director, Department of Natural Resources
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FOREWORD

The Colorado Department of Natural Resources is pleased to present the Colorado Geological Survey Open File Report 06-6, *Geologic Map of the Palmer Lake Quadrangle, El Paso County, Colorado.* Its purpose is to describe the geologic setting and mineral resource potential of this 7.5-minute quadrangle located in the northwestern part of El Paso County. 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, mineral resource development, and ground water exploration. Field work for this project was conducted during the summer of 2005 by CGS staff geologists John Keller and Matt Morgan, consulting geologist Jon Thorson, and CGS summer field geologist Neil Lindsay. Peter Barkmann, staff hydrogeologist with the Colorado Geological Survey, completed the Water Resources section of the booklet.

This mapping project was funded jointly by the U.S. Geological Survey through the STATEMAP component of the National Cooperative Geologic Mapping Program, which is authorized by the National Geologic Mapping Act of 1997, Agreement No. 05HQAG0064, and the Colorado Geological Survey using the Colorado Department of Natural Resources Severance Tax Operational Funds. The CGS matching funds come from the severance tax paid on the production of natural gas, oil, coal, and metals.

Vince Matthews
State Geologist and Division Director

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LOCATION AND GENERAL GEOLOGY

The Palmer Lake quadrangle is located in the northwestern corner of El Paso County, Colorado, along the eastern flank of the Rampart Range (fig. 1). The U.S. Air Force Academy campus is in the southeastern part of the quadrangle. The small towns of Palmer Lake and Monument are in the northeastern part of the map area. Interstate Highway 25 is located just east of the quadrangle boundary. The Mount Herman Road transects the quadrangle from east to west and is the only public road passable by passenger vehicle to provide access into the Rampart Range.

The Rampart Range rises abruptly west of the Rampart Range Fault, which transects the quadrangle north to south. East of the fault zone is the comparatively subdued topography of the Colorado Piedmont. Elevation within the quadrangle ranges from roughly 6,800 feet along Hay Creek and Beaver Creek in the southeastern part of the quadrangle to 9,378 feet on an unnamed knoll along the Schubarth Trail in the southwestern part of the quadrangle. Mount Herman (fig. 2), which rises to 9,063 feet along the range front, is the most prominent peak in the quadrangle as viewed from the flatter and more populated eastern part of the mapped area and Interstate 25. Several creeks and ephemeral streams that originate in the Rampart Range flow from west to east across the quadrangle and are part of the Arkansas River drainage basin. The principal streams and drainages within the quadrangle are, from north to south, Monument Creek, North Monument Creek, North and South Beaver Creeks, Hay Creek, Deadmans Creek, and Goat Camp Creek. Most of the forested land in the Rampart Range is administered by the U.S. Forest Service (Pike Peak Ranger District, Pike National Forest). The flatter land in the eastern one-third of the quadrangle, aside from the U.S. Air Force Academy, is mostly privately owned.

The oldest rocks exposed in the Palmer Lake quadrangle are granitic rocks of the late Mesoproterozoic Pikes Peak batholith, which forms the Rampart Range. Rocks of the batholith are faulted against Laramide-age synorogenic sedimentary rocks of the Dawson Formation along the Rampart Range Fault, a major north-south reverse fault that separates the Rampart Range from the Denver Basin. The fault also serves as the physiographic demarcation between the Colorado Piedmont and the Rampart Range physiographic provinces.

The Dawson Formation forms the bedrock in the eastern one-third of the Palmer Lake quadrangle. A 140- to 180-feet-thick remnant of Lower Paleozoic strata rests unconformably on Pikes Peak Granite in a fault-bounded block just west of the Air Force Academy, near Deadmans Lake. A wedge of Upper Cretaceous marine sedimentary strata is present in a tectonic sliver along the Rampart Range Fault in the northwestern corner of the Air Force Academy.

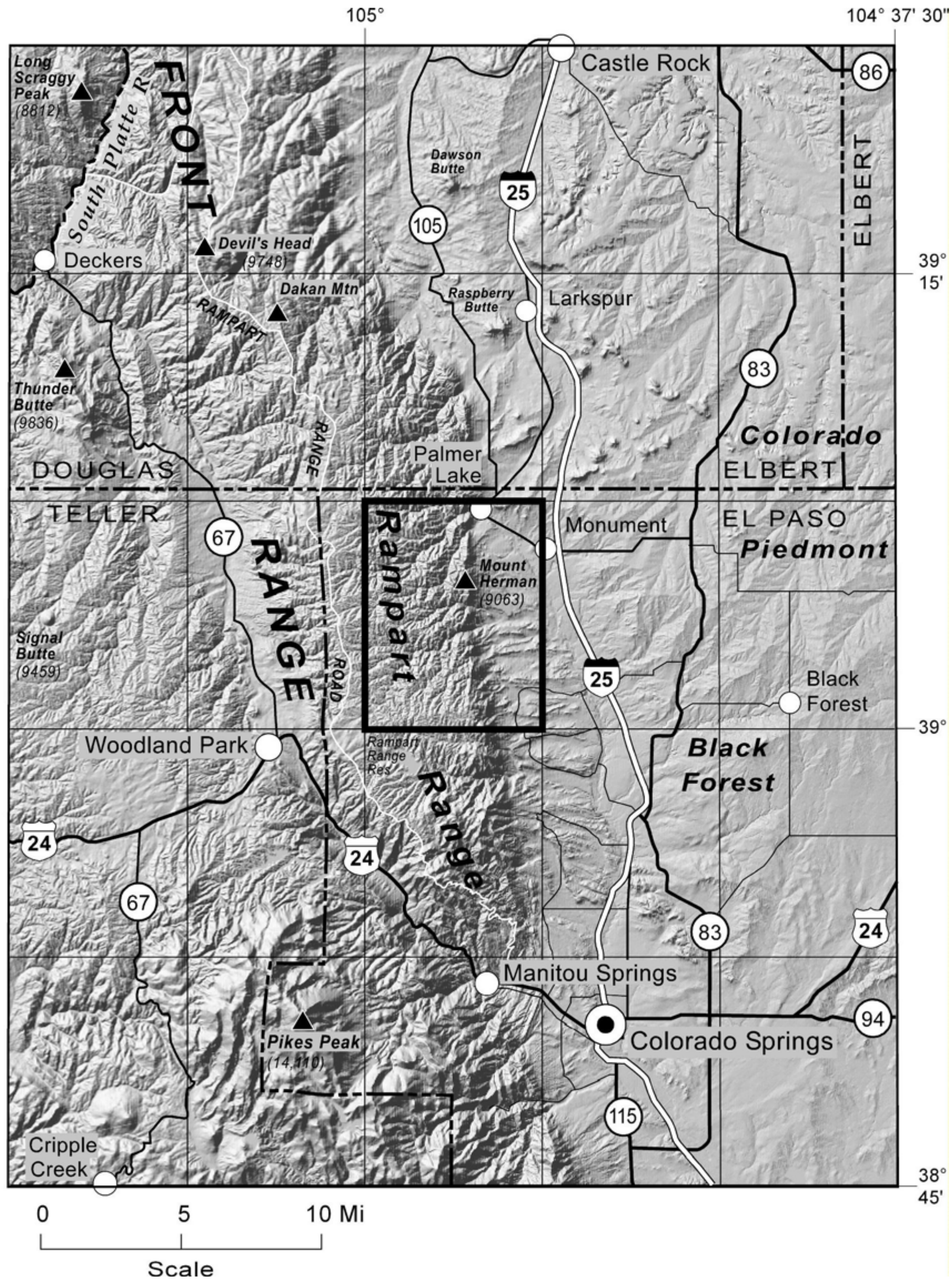

Figure 1. Shaded relief map of the region surrounding the Palmer Lake quadrangle shows cities and towns, major roads, and other geographic features. Palmer Lake quadrangle in bold black outline.

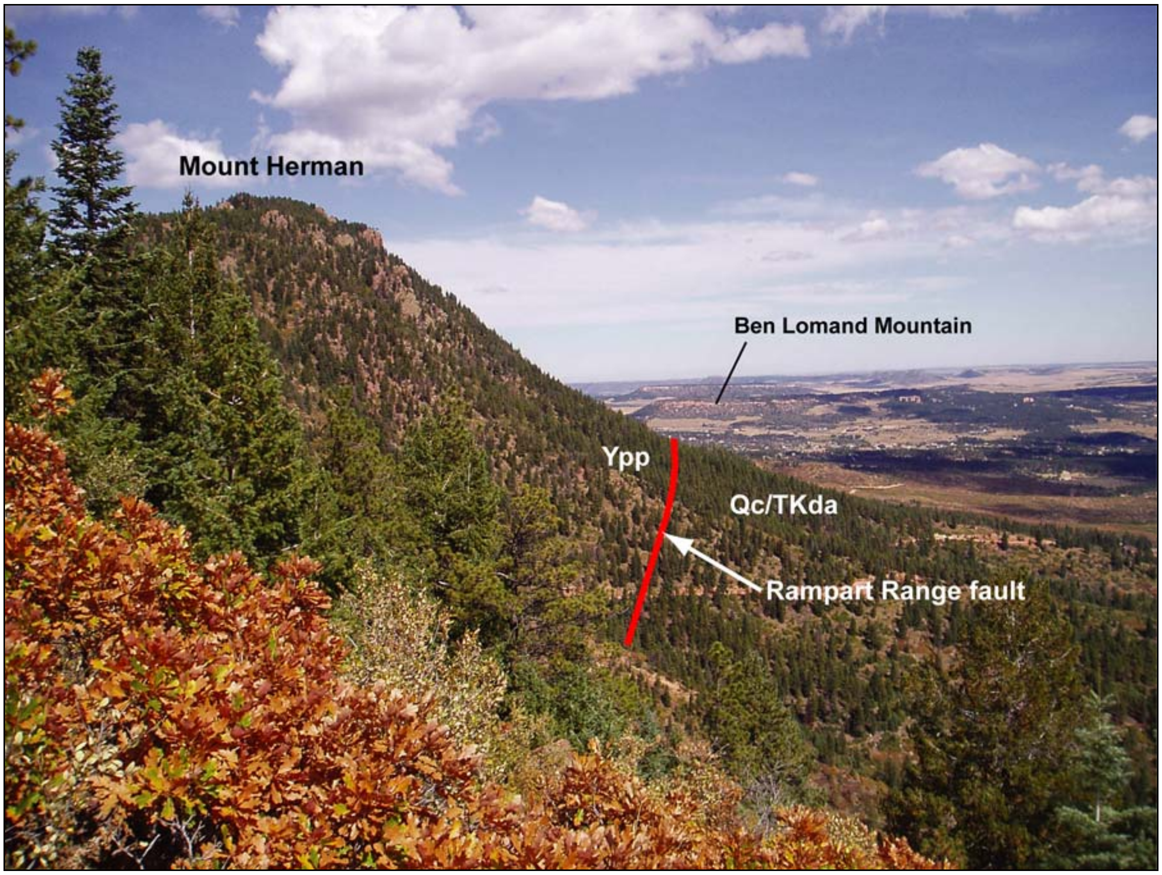

Figure 2. Photograph looking north-northeast along the eastern margin of the Rampart Range in the Palmer Lake quadrangle shows the approximate trace of the Rampart Range Fault, Mt. Herman, and Ben Lomand Mountain on the Colorado Piedmont. Ypp = Pikes Peak Granite, Qc = colluvial deposits, TKda = Dawson Formation.

In the Rampart Range about one mile south of the Mount Herman Road, two small areas of Miocene(?) fluvial gravel rest on the Pikes Peak Granite above an erosion surface that is either of late Eocene age (Epis and Chapin, 1975; Chapin and Kelley, 1997) or Miocene age (Steven and others, 1997). These deposits are thought to be thin, erosional remnants of gravels deposited in a major Miocene drainage system (paleovalley) that transported sediment derived from the Sawatch and Mosquito ranges, South Park, and the Cripple Creek area eastward to the plains (Steven and others, 1997).

Quaternary surficial units, predominantly fluvial in origin, form laterally extensive and sometimes thick deposits in the eastern one-third of the map area. Several ages and levels of fluvial gravels are mapped. Colluvium and localized mass-wasting deposits mantle the steep eastern margin of the Rampart Range.

SCOPE OF WORK

The present study focuses on geologic mapping of the Palmer Lake 7.5-minute quadrangle. Field work was undertaken during the summer and early fall of 2005. The geology was mapped on U.S. Forest Service color aerial photographs (1:24,000-scale) taken in 1975 and 1977. Bedrock mapping in the Rampart Range and along the Rampart Range Fault was completed by John Keller and Neil Lindsay. Quaternary deposits throughout the quadrangle were mapped and described by Matt Morgan, who also wrote the Geologic Hazards section of this report. Jon Thorson mapped and described the Dawson Formation which underlies the eastern one-third of the quadrangle. Peter Barkmann wrote the Water Resources section of this report. Map unit contacts were transferred from photogrammetric models of annotated aerial photographs to the topographic map of the Palmer Lake quadrangle using the ERDAS (Earth Resource Data Analysis System) stereographic program. Surficial deposits with maximum thicknesses of less than about 5 feet were generally not mapped. Bedrock outcrops and surficial deposits with a map width less than about 50 feet generally are not depicted on the map. Thin but important bedrock units, such as pegmatites that were mined in the past, and the sandstone dike near the mouth of Limbaugh Canyon, are represented on the map as single lines. The cultural features of the topographic base map were revised in 1994. Thus, roads, reservoirs, and buildings constructed after 1994 are not on the map base. Some human-made deposits that postdate the aerial photography also are not on the map.

PREVIOUS GEOLOGIC MAPPING

The region that includes the Palmer Lake quadrangle was mapped at a scale of 1:48,000 for the Castle Rock Folio of the Geologic Atlas of the United States (Richardson, 1915). Trimble and Machette (1979a, 1979b) compiled 1:100,000 scale maps of the region as part of a series of geologic maps of the Front Range Urban Corridor. Varnes and Scott (1967) prepared a 1:12,000-scale geologic map of the U.S. Air Force Academy grounds. The Denver 1° x 2° sheet 1:250,000-scale geologic map (of which the Palmer Lake quadrangle is a part) was mapped by Bryant and others (1981). Recent detailed geologic mapping in the Colorado Springs-Monument-Castle Rock area at 1:24,000 scale has been conducted by the Colorado Geological Survey (fig. 3). The Woodland Park quadrangle southwest of the Manitou Springs quadrangle was mapped in reconnaissance fashion by the U.S. Geological Survey (Wobus and Scott, 1977).

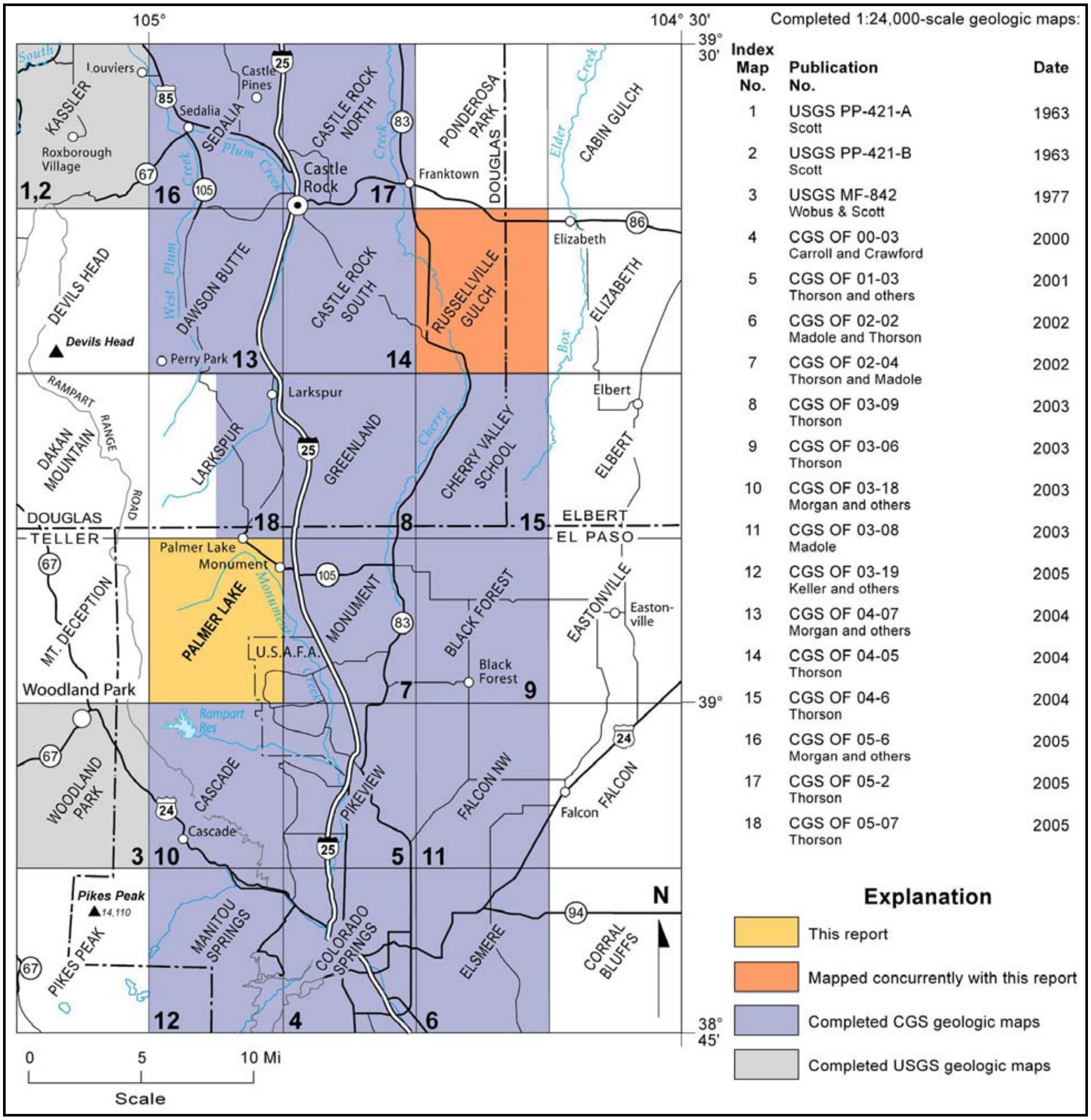

Figure 3. Location map and index of selected published 1:24,000-scale geologic maps in the vicinity of the Palmer Lake quadrangle.

ACKNOWLEDGMENTS

This mapping project was funded jointly by the Colorado Geological Survey and U.S. Geological Survey through the STATEMAP program of the National Cooperative Geologic Mapping Program under agreement no. 05HQAG0064. We are grateful to Chuck Kluth, Distinguished Scientist at the Colorado School of Mines for reviewing and improving this publication. Consulting geologist and Cheyenne Mountain High School science teacher Jay Temple, co-author of the CGS geologic map of the adjacent Cascade quadrangle (Morgan and others, 2003), helped with field identification of several ambiguous and structurally deformed outcrops of Cretaceous rocks along the Rampart Range front. CGS staff geologists Dave Noe and Chris Carroll provided helpful advice on Cretaceous sedimentary rocks along the base of the Front Range. Jeff Hovermale of the Pikes Peak Ranger District, U.S. Forest Service provided information about newly proposed oil and gas drilling in the Rampart Range. Cheryl Brchan, who retired from CGS in February after 30 years of service, provided much GIS and cartographic support. Larry Scott produced several figures for the report. Jane Ciener of Menlo Park, California was the technical editor. Vince Matthews, State Geologist and Director of CGS, performed the final review of the map and text prior to publication. Jacob Baker scanned the aerial photographs, and Paula Stokes prepared the digital stereographic models in ERDAS. The City of Colorado Springs provided LIDAR data for the quadrangle. We thank the numerous private landowners who allowed access to and through their properties throughout the field season. We also thank Rick Mungo, director of the Farish Recreation Area (U.S. Air Force) and Steve Wallace of the U.S. Air Force Academy for allowing access to U.S. Air Force lands.

DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSITS

Surficial deposits shown on the map are generally more than five feet thick but may be thinner locally. Residuum, sheetwash, colluvium, and artificial fills of limited extent were not mapped. Contacts between surficial units may be gradational, and mapped units locally may include small deposits of other types (for example, an area mapped as landslide may have small pockets of colluvium that are not mapped separately). Age divisions for the Holocene used in the Palmer Lake quadrangle are arbitrary and informal. They are based chiefly on paleontological data compiled for the southwestern United States. Relative age assignments for surficial deposits are based primarily on the degree of erosional modification of original surface morphology, height above modern stream levels, degree of dissection and slope degradation, and soil development. Clast size is based on the modified Wentworth scale. The Front Range piedmont stratigraphic nomenclature of Quaternary alluvial deposits was established by Hunt (1954) and Scott (1960). Varnes and Scott (1967), Trimble and Machette (1979a), and Bryant and others (1981) applied this nomenclature to Quaternary deposits in the Palmer Lake quadrangle. To retain consistency with previous Colorado Geological Survey geologic maps in the Castle-Rock-Colorado Springs area, the formal names for alluvial deposits were not used in the Palmer Lake quadrangle. Colors used to describe the deposits are from the Munsell series (wet; Geological Society of America, 2000).

HUMAN-MADE DEPOSITS

af **Artificial fill (latest Holocene) —** Rip rap, engineered fill, and refuse placed during construction of roads, railroads, buildings, dams, and landfills. Generally consists of unsorted silt, sand, clay, and rock fragments. This unit may also include areas of construction and quarrying operations where original deposits have been removed, replaced, or reworked. The average thickness of the unit is less than 30 feet.

ALLUVIAL DEPOSITS **–** Silt, sand, and gravel deposited in stream channels, on flood plains, on pediments, and as sheetwash along valley sides of creeks. Terrace alluvium and related pediment gravel deposits along these creeks were deposited mostly during periods of effective wetter climate that coincide with Pleistocene glaciations (Madole, personal communication, 2005). The approximate terrace heights reported for each unit are the elevation differences measured between the creek bed and the top of the original or remnant alluvial surface adjacent to the creek. Thickness reported is the maximum exposed thickness of the unit.

Qa **Stream-channel, flood-plain, and terrace alluvium, undivided (Holocene and late Pleistocene)** — Clast-supported, pebble, cobble, and rare boulder gravel in a sandy silt matrix. Terrace alluvium rests a maximum of 10 feet above modern stream level. May be locally interbedded with and commonly overlain by sandy silt and silty sand. Clasts are subangular to well rounded and of varied lithology, reflecting the diverse types of bedrock within their provenance. Locally, unit may include organic-rich sediments. Deposits may be interbedded with fan deposits (Qf), colluvium-sheetwash (Qcs), sheetwash-colluvium (Qsw), and alluvium-colluvium (Qac). Maximum thickness of this unit may exceed 20 feet. Areas mapped as Qa may be prone to flooding, erosion, and sediment deposition. The unit is a potential source of commercial sand and gravel.

Qa_1 **Alluvium one (late to early Holocene)** — Yellow to dark-brown, poorly to moderately sorted, unconsolidated clay silt, sand, gravel, and sparse boulders deposited as clast- or matrix-supported alluvium in creek beds, stream terraces, or in undissected swales or low-lands in valleys. Clasts are subangular to well rounded and of varied lithology. Deposit commonly includes organic-rich layers interbedded with sand and gravel lenses. Terrace heights reach as much as 8 feet above current stream level. Maximum thickness of unit locally exceeds 10 feet. The alluvium commonly forms steep-sided walls in arroyos. The unit is generally correlative, by virtue of height and soil characteristics, with the Husted Alluvium of Varnes and Scott (1967) on the U.S. Air Force Academy and the Piney Creek Alluvium of the Denver area (Scott and Wobus, 1973). The unit also contains modern alluvium in the currently active flood plain; due to its limited extent, the modern alluvium was not mapped separately. Unit Qa_1 is a potential source of commercial sand and gravel.

Qa_2 **Alluvium two (late Pleistocene)** — Dark-yellow to dark-brown, poorly to moderately sorted, poorly consolidated clay, silt, sand, gravel, and sparse boulders deposited in stream terrace deposits and in undissected alluvium in valley headwaters. Clasts are subangular to well rounded and have varied lithology. Deposit commonly includes organic-rich layers interbedded with sand and gravel lenses. Terrace heights reach as much as 15 feet above current stream level. Maximum thickness of unit locally exceeds 15 feet. The unit is correlative, by virtue of height and soil characteristics, with the Broadway Alluvium of the Denver area (Scott and Wobus, 1973). Holliday (1987) determined that deposition of the Broadway Alluvium ceased by 11,000 to 10,000 yr B.P. ^{14}C (about 12,000 to 13,000 calendar years B.P.) on the basis of geoarchaeological (Clovis people artifacts) evidence found in the alluvium in the Greeley area. The soil profile of the unit is characteristic of deposits associated with the Pinedale glaciation, which began approximately 30,000 yr B.P. ^{14}C (about 35,000 calendar years B.P.) and ended prior to 12,000 yr B.P. ^{14}C (about 14,000 calendar years B.P.) (Madole, 1986). The unit is a potential source of commercial sand and gravel.

Qac **Stream alluvium and colluvium, undivided (Holocene and late Pleistocene)** — Stream channel, terrace, and flood-plain deposits along valley floors of ephemeral, intermittent, and small perennial streams, and colluvium along valley sides. May interfinger with stream alluvium (Qa), fan deposits (Qf), colluvium (Qc), sheetwash (Qsw), colluvium and sheetwash (Qcs) and landslides (Qls). Alluvium is typically composed of poorly to well sorted, stratified, interbedded, pebbly sand, sandy silt, and sandy gravel. Colluvium may range from unsorted, clast-supported, pebble to boulder gravel in a sandy silt matrix to matrix-supported, gravelly, clayey, sandy silt. Clasts have a wide range of lithologies dependent upon the local bedrock or surficial unit sources. Maximum thickness of the unit is approximately 20 feet.

Qsw **Sheetwash alluvium (Holocene and late Pleistocene)** — Yellowish-brown, poorly sorted sandy silt, clayey silt and sand with minor amounts of pebble-sized rock fragments. The sediment of this unit was transported and deposited principally by sheet flow. Lithology of sediments is dependant upon the local bedrock or surficial unit sources; however, a majority of the sheetwash deposits are derived from the Dawson Formation. Sheetwash alluvium also occurs in stream, alluvial-fan, and landslide deposits and may include local loess deposits that are too small to show separately. Maximum thickness of this unit is about 10 feet. The unit is also common along the foot slopes of valley sides and topographic depressions on slopes. Areas mapped as sheetwash are susceptible to runoff following large precipitation events.

Qf_1 **Alluvial-fan deposit one (late Holocene)** — Dark-yellow, brownish-gray to reddish-brown, poorly to moderately sorted, poorly consolidated clay, silt, sand, gravel, and boulders deposited in/on alluvial fans at the mouths of perennial streams. They have a fan shape and consist of subangular to well-rounded clasts of varied lithology; however, on the piedmont the Dawson Formation is a major constituent. Sediments are deposited primarily by streams with significant input from sheetwash, debris flows, and hyperconcentrated flows. Deposits locally exceed 10 feet in thickness. Areas mapped as alluvial fans are subject to future flash floods and debris flow events. Deposits may be prone to collapse, hydrocompaction, or slope failure when wetted or loaded.

Qf_2 **Alluvial-fan deposit two (early Holocene to late Pleistocene)** — Dark-yellow to dark-brown, poorly to moderately sorted, poorly consolidated clay, silt, sand, gravel, and boulders deposited as alluvial fans at the mouths of perennial streams. Clasts are subangular to well rounded and have varied lithology dependant upon source area; however, on the piedmont the Dawson Formation is a major constituent. They have a fan-like shape but are more dissected than younger Qf_1 deposits and they are usually cut by unit Qa_1. Sediments are deposited primarily by streams with significant input from sheetwash, debris flows, and hyperconcentrated flows. The apices of the fans are as much as 15 feet above modern streams. Deposits locally exceed 12 feet in thickness. Areas mapped as alluvial fans are subject to future flash floods and debris flow events. Deposits may be prone to collapse, hydrocompaction, or slope failure when wetted or loaded.

Qf_3 **Alluvial-fan deposit three (late Pleistocene)** — Dark grayish-brown to yellow-reddish-brown, poorly to moderately sorted, moderately consolidated clay, silt, sand, gravel, and boulders deposited as alluvial fans at the mouths of perennial streams. Clasts are subangular to well rounded and have varied lithology dependant upon source area; however, on the piedmont the Dawson Formation is a major constituent. They no longer have a fan-like shape and are cut by unit Qa_2. Sediments are deposited primarily by streams with significant input from sheetwash, debris flows, and hyperconcentrated flows. The upper surface of the fan is as much as 55 feet above modern streams. Deposit locally exceeds 20 feet in thickness. Areas mapped as alluvial fans are subject to future flash floods and debris flow events. Deposits may be prone to collapse, hydrocompaction, or slope failure when wetted or loaded.

Qf **Alluvial-fan deposits (Holocene to late Pleistocene)** — Yellow-brown to reddish-brown, poorly sorted to moderately sorted, matrix-supported, gravelly, sandy silt to clast-supported, pebble and cobble gravel in a sandy silt or silty sand matrix. Clasts are mostly sub-angular to well rounded and are composed of granitic bedrock. Unit Qf is located in sec. 5, T. 11 S., R. 67 W., to the northwest of the town of Palmer Lake. The unit overlies Qg_2, so the age must be younger than middle Pleistocene. Sediments are deposited primarily by sheetwash, with minor input from perennial streams. The maximum estimated thickness for unit Qf is about 20 feet. Large precipitation events may trigger future deposition in areas underlain by alluvial-fan deposits. Deposits may be prone to collapse, hydrocompaction, or slope failure when wetted or loaded.

Gravel deposits (middle Pleistocene to late Pliocene) — Partly dissected remnants of four levels of older gravel deposits are preserved along Fountain and Monument Creeks and on the piedmont. Finlay (1916) recognized two of these "mesa gravels" on the basis of on their distinctive topographic form and suggested a fluvial origin. Varnes and Scott (1967) identified a third partially dissected gravel deposit at lower elevation and from youngest to oldest formally named them the Pine Valley Gravel, Lehman Ridge Gravel, and Douglass Mesa Gravel (table 2). They classed them as "pediment gravels." Scott and Wobus (1973) referred to all three deposits as "alluvial terrace or pediment gravel" and correlated them with similar deposits in the Denver area that were formally named the Slocum Alluvium, Verdos Alluvium, and Rocky Flats Alluvium by Scott (1960, 1963b). Additionally, a higher and fourth level of gravel, the "Nussbaum Formation" near Pueblo was reinterpreted by Scott (1963c, 1982) and renamed the "Nussbaum Alluvium" of possible late Pliocene to early Pleistocene age. This is the highest and oldest deposit in the sequence of alluviums described by Scott (1960, 1963a, 1963b), and is located 450 feet above modern streams in the Denver area. The deposits may form terraces and in many places the surface underlying the deposit forms a pediment.

Qg_1 **Gravel deposit one (middle Pleistocene) —** Light-reddish-brown to yellowish-brown, poorly sorted, moderately to poorly stratified pebble and cobble gravel primarily derived from granitic bedrock, as well as layers of clay, silt, sand and clay clasts derived from arkosic bedrock. Clasts are subrounded to rounded and are coated with a thin (less than 0.02-inch), discontinuous rind of calcium carbonate. Matrix typically consists of feldspar and quartz sand derived from weathered clasts. The unit is richer in boulders and less stratified toward the mountain front and contains local debris flow deposits. Top of pediment gravel is 20 to 60 feet above adjacent modern streams. The unit locally exceeds 10 feet in thickness. Unit is correlated with the Pine Valley Gravel at the U.S. Air Force Academy (Varnes and Scott, 1967) and with the Slocum Alluvium (Scott and Wobus, 1973). Gravel deposit one is considered to be middle Pleistocene in age on the basis of local stratigraphic position and soil development. Scott (1960) considered the Slocum Alluvium to be Illinoian or Sangomon in age on the basis of stratigraphic position, mollusks, and pre-Wisconsin age soil profile (Varnes and Scott, 1967). Scott and Lindvall (1970) collected a bison horn core from the lower part of the Slocum Alluvium near the Arkansas river that yielded calibrated uranium-series age of 190 ± 50 ka (Szabo, 1980). The deposit forms a stable building surface, but excavations may be prone to slumping. The unit is a source of sand and gravel.

Qg_2 **Gravel deposit two (early middle Pleistocene) —** Reddish-brown, poorly sorted, moderately to poorly stratified pebble, cobble, and boulder gravel primarily derived from granitic bedrock. Basal portion of unit contains layers of clay and silt interbedded with coarse-grained sand, cobble, and rare boulder gravels. Many clasts are coated with a thin (0.05-inch), discontinuous rind of calcium carbonate. Matrix typically consists of feldspar and quartz sand derived from weathered clasts. Becomes richer in boulders and less stratified toward mountain front. Top of the gravel deposit is 100 to 230 feet above adjacent modern streams. The unit locally exceeds 15 feet in thickness. Unit correlates with the Douglass Mesa Gravel at the U.S. Air Force Academy (Varnes and Scott, 1967) and the Verdos Alluvium of the Denver area (Scott and Wobus, 1973). In the Denver area, the upper part of the Verdos Alluvium contains Lava Creek B ash (Scott, 1960), which was recently dated at 640,000 YBP (Lanphere and others, 2002). The unit is considered to be early middle Pleistocene on the basis of local stratigraphic position, soil development, and contained Lava Creek B ash. This unit forms a stable building surface; however, excavations may be prone to slumping. Unit is a source of sand and gravel.

Qg_3 G**ravel deposit three (early Pleistocene)** — Reddish-brown, poorly sorted, moderately to poorly stratified pebble, cobble, and boulder gravel primarily derived from granitic bedrock. Clasts are highly weathered and are coated with a 0.05-inch, discontinuous rind of calcium carbonate. Matrix typically consists of feldspar and quartz pebbles derived from weathered clasts. Boulders become larger and more abundant and the deposit becomes less stratified toward the mountain front. Top of gravel deposit is 250 to 350 feet above modern streams. Unit locally exceeds 30 feet in thickness. Unit is correlated with the Lehman Ridge Gravel of the U.S. Air Force Academy (Varnes and Scott, 1967), and the Rocky Flats Alluvium of the Denver area (Scott and Wobus, 1973). The unit is considered to be early Pleistocene in age on the basis of local stratigraphic position and soil development. Forms a stable building surface, but excavations may be prone to slumping. The unit is a source of sand and gravel.

QTg_4 **Gravel deposit four (early Pleistocene or late Eocene?)** — Reddish-brown, poorly sorted, poorly to moderately well-stratified sand, pebble, and cobble gravel that caps Ben Lomand Mountain in the northeast corner of the mapped area. Unit consists of clasts of the Pikes Peak batholith, the late Eocene Wall Mountain Tuff, the Dawson Formation, and lower Paleozoic sandstone and limestone. The unit also contains small amounts of chert pebbles and vein quartz. Clasts are occasionally coated with a discontinuous rind of calcium carbonate of variable thickness. Clast size ranges from sand-sized particles to boulders up to 3 feet in maximum diameter; the larger clasts are located near the base of the unit. Matrix typically consists of feldspar and quartz derived from weathered clasts; clay is also present. The top of the unit is approximately 450 feet above adjacent modern streams. The unit locally exceeds 60 feet in thickness. Soil development on the top of the unit is very weak, most likely indicating the surface of the unit is reworked. A reddish-brown, 5-foot thick clay-rich zone is present at the contact with the underlying Dawson Formation. The unit was correlated with the Verdos Alluvium of the Denver area by Scott and Wobus (1973). We suggest this deposit may either be the Castle Rock Conglomerate or the equivalent of the late Pliocene-early Pleistocene Nussbaum Alluvium of the Denver area. The diverse clast types are nearly identical to that of the Castle Rock Conglomerate at its type locality, especially the presence of Wall Mountain Tuff, which is unique to this unit. Its position in the landscape high (over 450 feet above adjacent modern streams) is similar to the height of the Castle Rock Conglomerate (approx. 430 feet above adjacent modern streams) near the town of Castle Rock and Nussbaum Alluvium (500-700 feet above adjacent modern streams (Morgan and others, 2003)) in the Cascade quadrangle. The direction of transport of this unit is unknown; however, the only sources for the clast type assemblage are to the north, west, and southwest. Forms a stable building surface, but excavations may be prone to slumping. The steep slopes surrounding Ben Lomand Mountain are prone to rockfall and rock avalanches. The unit is a potential source of sand and gravel.

Tg **Gravel (late Tertiary) —** Soft, pink and light-gray, unconsolidated, fluvial bouldery and cobbly pebble gravel exposed approximately ½-mile north of the intersection of secs. 1 and 2, T. 12 S., R. 68 W. Clasts, as large as 2 feet in exposed diameter, consist mostly of rounded to subrounded Precambrian rocks of the Pikes Peak batholith. Unit includes clasts of metasedimentary Precambrian rocks derived from areas perhaps to the south and volcanic rocks probably derived from the latest Eocene-early Oligocene Thirty-nine Mile volcanic field about 20 miles west of the mapped area (Scott and Wobus, 1973; Mertzman and others, 1994; Steven and others, 1997). The deposit occupies stream channels in a paleovalley. The erosion surface at the base of the deposit represents the surface widely reported capping the Rampart Range (for example, Epis and others, 1980; Steven and others, 1997). This surface could be early Tertiary (Epis and others, 1980) or, more probably, late Tertiary age (Steven and others, 1997). Taylor (1975), and more recently Steven and others (1997), considered the deposits to be the lateral equivalent of the latest Miocene Ogallala Formation of the Great Plains. A soil profile examined on the deposit under coniferous forest consists of a 3-inch-thick A-horizon, a 5-inch-thick E-horizon, and a 10-inch-thick Bt-horizon underlain by a 4-inch thick Bt2-horizon. Munsell colors (wet; Geological Society of America, 2000) range from 5YR 5/4 (reddish brown) for the Bt2-horizon, to 7.5 YR 4/3 (brown) for the A-horizon. The structure of the Bt2-horizon is angular to subangular blocky with clay films coating the faces of peds (soil structure unit) and individual grains. When wetted, the soil from the Bt2-horizon supports a cube form due to the very high clay content. Soil development on these deposits is much stronger than soils developed on the middle-early Pleistocene Qg_3. Weathering rinds on granitic clasts range from greater than 0.02 to 0.10 inches and as much as 0.4 inches on volcanic clasts. Degree of soil development, weathering rinds, stratigraphic position, and presence of volcanic clasts suggest this deposit is most likely late Tertiary. The maximum thickness in the mapped area is approximately 15 feet.

MASS-WASTING DEPOSITS – These deposits consist of earth materials that were transported downslope primarily by gravity and not within or under another medium, such as water or ice. Some of these deposits have moved by creep, which is a slow, gradual, progressive downslope movement of earth materials.

Qcs **Colluvium and sheetwash alluvium deposits, undivided (Holocene and late Pleistocene)** — This unit is composed of weathered bedrock fragments that have been transported downslope primarily by gravity and sheetwash. Colluvium ranges from unsorted, clast-supported, pebble to boulder gravel in a silty sand matrix to matrix-supported gravelly, clayey, silty sand. It is generally unsorted to poorly sorted, contains angular to subangular clasts, and is weakly stratified. Colluvial deposits derived from alluvial deposits contain rounded to subrounded clasts. Colluvium of large cobble- and boulder-sized rock fragments may include rockfall debris. The units may contain small landslides of limited extent. Sheetwash alluvium is common on slopes with less than a 10 percent grade below hills of granitic bedrock. Clast lithology is variable. Colluvium and sheetwash deposits may grade into and interfinger with sheetwash alluvium (Qsw), stream alluvium (Qa), stream alluvium and colluvium (Qac), alluvial-fan (Qf), and landslide deposits (Qls). Maximum thickness of this unit is approximately 20 feet. Areas mapped as colluvium and sheetwash are susceptible to future colluvial and sheetwash alluvial deposition and locally are subject to debris flows and rockfall. Colluvium and sheetwash deposits may be sources of aggregate, especially grüs derived from the weathering of Pikes Peak Granite.

Qc_1 **Colluvium deposit one (Holocene to late Pleistocene)** — This unit is composed of weathered bedrock fragments that consist of grayish-brown, yellowish-brown, to reddish-brown, poorly sorted, clast- to matrix-supported, pebble to boulder gravel in a sandy silt matrix to matrix-supported, gravelly, clayey, sandy silt. Unit contains well-rounded to subangular clasts. The rounded clasts are most likely granite corestones that weather to a spheroidal shape; these are abundant along the range front. The angular clasts are fragments of fractured granite, mainly from highly fractured areas proximal to the Rampart Range Fault. Clast lithologies are predominantly granites from the Pikes Peak batholith and minor amounts of Dawson Formation. Weathering rinds measured on granitic clasts in the upper 2-feet of the deposit range from 0-0.2 inches thick; clasts are pockmarked near the top of the deposit and are heavily disintegrated lower. The surface of Qc_1 is lower in the landscape when compared to unit Qc_2 and is closer to the range front escarpment. Where present, the soil profile appears to be of late Pleistocene to Holocene age. Units Qc_1 and Qc_2 differ from the Qg deposits by their sparse and poorly defined cross-stratification and their more angular clasts. Also, colluvial units Qc_1 and Qc_2 are not associated with major streams or drainages. Gravitational transport was clearly the dominant process; however, this is not to say that alluvial processes did not take place as localized scours and debris-flow deposits occur within units Qc_1 and Qc_2. Thickness of unit Qc_1 ranges from a thin veneer over bedrock to more than 30 feet. The unit is thickest at the slope break near the base of the range front escarpment. Colluvium of large cobble- and boulder-sized rock fragments may include rockfall debris. Areas mapped as colluvium are susceptible to future rockfall events.

Qc_2 **Colluvium deposit two (middle to late Pleistocene)** — This unit is composed of weathered bedrock fragments that consist of reddish-brown to yellowish-red, poorly sorted, clast- to matrix-supported, pebble to boulder gravel in a sandy silt matrix to matrix-supported, gravelly, clayey, sandy silt. Unit contains well-rounded to subangular clasts. The rounded clasts are most likely granite corestones that weather to a spheroidal shape and are abundant along the range front. The angular clasts are fragments of granite fractured from movement on the Rampart Range Fault. Clast lithologies are predominantly granites from the Pikes Peak batholith and minor amounts of Dawson Formation. Weathering rinds measured on granitic clasts in the upper 3 feet of the deposit range from 0.07-0.5 inches thick; clasts are slightly to heavily disintegrated. The surface of Qc_2 is higher in the landscape when compared to unit $Qc_1$and is farther from the range front escarpment. This difference in elevation is due to erosion of the underlying Dawson Formation and weathering resistance of the granitic clasts (see fig. 4 for explanation). Where present, the age of the soil profile is probably middle to late Pleistocene. Units Qc_1 and Qc_2 differ from the Qg deposits by their sparse and poorly defined cross-stratification and their more angular clasts. Also, colluvial units Qc_1 and Qc_2 are not associated with major streams or drainages. Gravitational transport was clearly the dominant process; however, alluvial processes, evidenced by localized scours and debris-flow deposits, occur within units Qc_1 and Qc_2. Thickness of unit Qc_2 ranges from a thin veneer over bedrock to more than 30 feet. The unit is thickest at the slope break near the base of the range front escarpment. Colluvium of large cobble- and boulder-sized rock fragments may include rockfall debris. Areas mapped as colluvium are susceptible to future rockfall events.

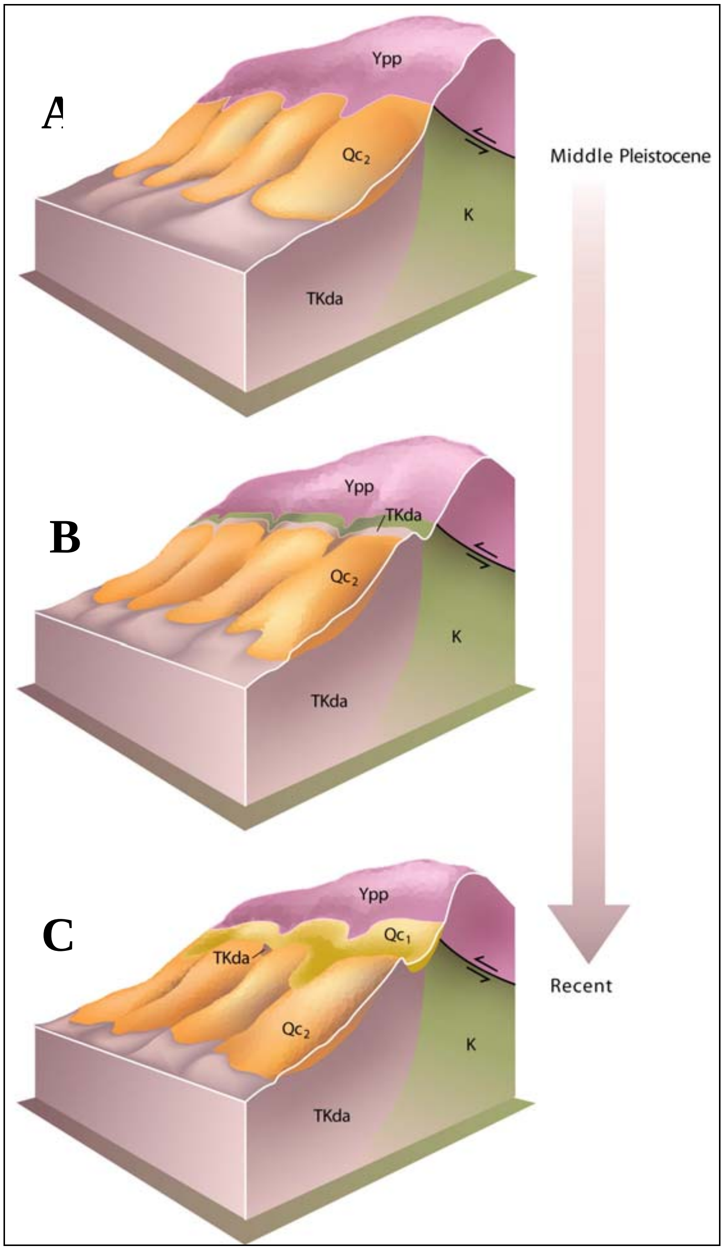

Figure 4. Diagrammatic block diagram of colluvium flatiron formation and mountain front recession. Diagram A shows the deposition of unit Qc_2, possibly during the middle Pleistocene, by erosion of the fractured and weathered Pikes Peak Granite. The resistant colluvium covers the less-resistant Dawson Formation (TKda). Further erosion of unit Qc_2 (diagram B) down the hillslope exposes the underlying Dawson Formation and Cretaceous rocks which erode, leaving the Qc_2 armored slope suspended from the mountain front as a colluvium flatiron. Erosion also causes the mountain front to steepen slightly (diagrams B and C). More recent deposition (diagram C) of younger colluvium (Qc_1) covers the modern hillslope and parts of unit Qc_2; however small outcrops of TKda remain exposed.

Qc **Colluvium deposits, undivided (Holocene to late Pleistocene)** — This unit is composed of weathered bedrock fragments that are reddish-brown to yellowish-brown, poorly sorted, clast-supported, pebble to boulder gravel in a sandy silt matrix to matrix-supported, gravelly, clayey, sandy silt. Unit contains angular to subangular clasts and is weakly stratified. Colluvial deposits derived from alluvial deposits contain rounded to subrounded clasts. Lithology is dependant on local bedrock and surficial deposit sources. On the slopes of Ben Lomand Mountain, significant deposits of colluvium are mantled with cobble- and boulder-sized blocks of resistant Dawson Formation. Colluvium composed of large cobble- and boulder-sized rock fragments may include rockfall debris. Deposits locally exceed 25 feet in thickness. Areas mapped as colluvium are susceptible to future rockfall events.

Qls **Landslide deposits (Holocene to late Tertiary) —** Heterogeneous deposits consisting of unsorted and unstratified clay, silt, sand, and angular, cobble- to boulder-sized rock fragments. Unit includes rotational slides and areas of creep. In most places, landslides show obvious geomorphic expression that disrupts the profile of the slopes. Generally, head scarps (near-vertical detachment scars exposed at the top of and sides of the landslides) are readily recognizable. Other common diagnostic features include hummocky topography, closed depressions, and pressure ridges at the toe of the mobilized mass. All of the landslides are composed of fragments of Pike Peak Granite; some of the bedrock fragments may be weathered to grüs. See the "Geologic Hazards" section for a discussion of landslides within the mapped area. Landslide areas are subject to future movement during episodes of heavy rain or snowfall or may be reactivated by human-made disturbances such as cutting of slopes for roads, housing developments, irrigation systems, and septic systems. Landslide deposits are prone to settlement when loaded or wetted. Maximum thickness of landslide deposits in the quadrangle locally exceeds 80 feet.

BEDROCK UNITS

$TKda_5$ **Dawson Formation, facies unit five (early to middle? Eocene) —** This facies unit of the upper part of the Dawson Formation is similar to facies units one and four. It was mapped as a separate unit because it follows the prolonged episode of weathering and oxidation that resulted in the regional paleosol at the top of facies unit four. On the basis of the descriptions of the paleosol and environmental interpretations of Farnham and Kraus (2002), the palynology of Nichols and Fleming (2002), the geochronology of Obradovich (2002), the magnetostratigraphy of Hicks and others (2003), and considerable additional sources, Raynolds and Johnson (2003, fig. 3, p. 176) have interpreted the hiatus represented by the Denver Basin regional paleosol to be 8 to 9 million years. Facies unit five was deposited above the paleosol by energetic streams that carried coarse-grained arkosic sediments into the basin after the depositional hiatus had ended.

Unit TKda5 is dominated by very thick bedded to massive, cross-bedded, light-colored arkoses, pebbly arkoses, and arkosic pebble conglomerate, but the individual grains of feldspar or granite are often pink instead of light gray to white as in units TKda1 and TKda4. Facies unit five contains common beds of white to light-tan, fine- to medium-grained feldspathic, cross-bedded friable sandstone. These sandstones are poorly sorted, have high clay contents, and are often thin or medium bedded; wavy bedding and ripple cross-laminations are common. Facies unit five also contains massive structureless beds interpreted to be the mudflows. Facies unit five is about 500 feet thick in the northeast part of the quadrangle; the top of the unit has been removed by erosion. Facies unit five is generally permeable, well drained, and has good foundation characteristics. Excavation may be difficult, even though the arkoses are friable and easily eroded on weathered outcrops. The massive mudflow beds may be well indurated and may require considerable effort to excavate. Facies unit five appears to be equivalent to the Dawson Arkose and/or Dawson aquifer in the Denver area (George VanSlyke, 2001, personal communication). Elephant Rock (fig. 5), a local landmark, is a natural arch eroded into facies unit five of the Dawson Formation in the northeastern part of the Palmer Lake quadrangle.

Figure 5. Elephant Rock natural arch, Dawson Formation facies unit five. Richardson (1915) photographed the same outcrop for the Castle Rock Geologic Atlas Folio and described it as “grotesque”.

TKda$_4$ Dawson Formation, facies unit four (Paleocene) — This facies unit of the upper part of the Dawson Formation is similar to facies unit one (TKda1) in the Monument quadrangle but becomes finer and more clay-rich in the Palmer Lake quadrangle and resembles facies unit three. Facies unit four is about 500 feet thick. The top of facies unit four is a strongly developed paleosol that was traced around the Denver Basin by Soister and Tschudy (1978). This paleosol is a recessive unit and may not be continuous, but artificial exposures allow it to be followed through the northeastern part the quadrangle. Here bright-maroon to dark-red, very clayey, coarse sandstone and fine-pebble conglomerate are interbedded with light-gray to pink, very coarse, pebbly arkose and pebble conglomerate in a sequence of strata about 40 feet thick. The reddish-colored zones are often mottled with yellow-brown and greenish-gray patches and are cut by root structures. These reddish-colored zones are very clayey and have very coarse sand-size grains or fine pebbles of clear and light- to dark-gray quartz in a matrix of red, maroon, yellow-brown, or greenish-gray sandy claystone. The quartz grains are generally matrix supported. In facies unit four, beds with very coarse sand-size grains and small pebbles are usually arkosic, contain abundant feldspar, and are grain supported. The reddish-colored paleosol zones are interpreted to be arkoses in which the feldspars have been altered to clay during protracted periods of weathering and oxidation leaving only the resistant quartz grains in a red clay matrix. Facies unit four is generally permeable, well drained, and has good foundation characteristics. Excavation may be difficult, even though the arkoses are friable and easily eroded on weathered outcrops. The massive mudflow beds may be hard and tough and may be well indurated and require considerable effort to excavate. Rock fall from cliffs in facies unit four poses a significant slope stability hazard in some areas. Facies unit four may be equivalent to the Dawson Arkose and/or Dawson aquifer in the Denver area (George VanSlyke, 2001, personal communication).

TKda$_3$ Dawson Formation, facies unit three (Paleocene) — This facies unit consists of sub-equal amounts of three lithologies: (1) thick and very thick-bedded, massive and cross-bedded, white, tan, and light-gray arkose and pebbly arkose; (2) thin to thick beds of light-green to olive-gray, clay-rich, fine- to medium-grained micaceous and feldspathic sandstone; and (3) thin to thick beds of dark-gray to greenish-gray sandy claystone. In the southeastern part of the Monument quadrangle the unit is 500 to 600 feet thick. It thins to the northwest into the Palmer Lake quadrangle as it interfingers with facies unit one and facies unit four.

The very thick-bedded, massive or cross-bedded, light-colored arkose beds in facies unit three resemble those in facies unit one but are finer grained and generally thinner. Most of the grains in these arkoses are less than ½-inch in diameter; a few pebbles are up to 1½ inches. The lithologies of the coarse grains are much more varied than those in the arkoses of facies unit one, with grains of quartz, white feldspar, pink feldspar, white granite, pink granite, and small amounts of tan vuggy dolomite and red, black, or orange-brown chert. The light-green to olive-gray, clay-rich, fine- to medium-grained micaceous and feldspathic sandstone and the dark-gray to greenish-gray sandy claystone resemble lithologies in the lower part of facies unit two in the Pikeview and Elsmere quadrangles to the south and southeast (Thorson and others, 2001; Madole and

Thorson, 2002). The sandstones and arkoses of facies three are generally stable and have good foundation characteristics. The finer grained, more clay-rich, lithologies should be expected to be less stable and may have high shrink-swell potential.

$TKda_1$ Dawson Formation, facies unit one (Upper Cretaceous to Paleocene) — This facies unit is composed of white to light-gray, cross-bedded or massive, very coarse arkosic sandstone, pebbly arkose, or arkosic pebble conglomerate. The facies unit contains occasional interbeds of thin- to very thin-bedded gray claystone and sandy claystone, or dark-brown to brownish-gray, organic-rich siltstone to coarse sandstone containing abundant plant fragments. Facies unit one comprises a coarse "mountain front" synorogenic deposit of sediments that were eroded from a rapidly uplifting Front Range, transported across an active fault zone along the mountain front, and deposited in the western part of subsiding Denver Basin (see fig. 13, Stratigraphy chapter of this report). Monument Rock, a local landmark, is a prominent outcrop of facies unit one (fig. 6). In the Monument quadrangle facies unit one is at least 700 feet thick in a water well in SW¼ SW¼ sec. 1, T. 12 S., R. 67 W. (Air Academy 2, Varnes and Scott, 1967, plate 8). On the basis of that data and more recent geologic mapping (Thorson and Madole, 2002; Thorson and others, 2001), the regional geometry of facies unit one indicates that it is thickest near the mountain front and thins toward the basin. Near the mountain front the unit may be over 900 feet thick. Mapping in the Palmer Lake quadrangle indicates that this facies was deposited immediately adjacent to the mountain front and forms a coarse grained equivalent of facies units three and four. Facies unit one is generally permeable, well drained, and has good foundation characteristics. Excavation may be difficult, even though on the weathered surfaces the arkoses are friable and easily eroded. The massive mudflow beds may be hard and tough and may require considerable effort to excavate. The finer grained interbeds may be less stable and may have greater shrink-swell properties than the arkoses. The block-failure of cliffs in facies one poses a significant slope stability hazard in some areas.

Figure 6. Photograph of Monument Rock, located south of the Mt. Herman Road in the Palmer Lake quadrangle. Monument Rock is composed of facies unit one of the Dawson Formation (TKda1). CGS geologist Matt Morgan helpfully indicates the location of the outcrop.

Kl **Laramie Formation (Upper Cretaceous) —** The Laramie Formation is exposed in the structurally complex area in sec. 5, T. 12 S., R. 67 W., in the northwestern part of the Air Force Academy. The best exposure of the unit in the map area is in an old, shallow excavation directly east of the low hogback of faulted Niobrara Formation. Beds of the Laramie Formation are here overturned, dipping steeply west. Because of faulting, the complete section of Laramie Formation is not exposed so the total thickness of the formation is not known. A small exposure of light-yellowish-brown Laramie Formation sandstone is exposed in a small erosional window through Quaternary cover in the area west of the thin, faulted slivers of Niobrara Formation and east of the other main splay of the Rampart Range Fault that separates Pikes Peak Granite from sedimentary strata. More complete exposures of the Laramie Formation in the Pikeview quadrangle to the southeast show that the total thickness is about 715 feet (Thorson and others, 2001). However, closer to the range front in the Cascade quadrangle, only the lower 115 feet of the formation is present (Morgan and others, 2003). Upper parts of the formation were probably removed by erosion close to the range front during Laramide deformation and uplift of the Rampart Range, prior to being buried with the coarse, syntectonic clastic sediments of the overlying Dawson Formation.

In the Palmer Lake quadrangle, the Laramie Formation is poorly consolidated and easily eroded compared to the adjacent low hogbacks of the Niobrara Formation and the Codell Sandstone. The Laramie Formation here consists mostly of white, very light gray, and light-yellowish-brown, fine-grained, well sorted, equigranular, non-calcareous, quartz sandstone. The sandstone is usually massive to faintly bedded. Areas of yellow-brown are due to iron oxide staining, particularly near fracture surfaces. Thin plates of dark orange-brown iron oxide-cemented sandstone were observed as surface float in a few places. A few thin beds of brownish-gray to dark-gray carbonaceous shale and sandy shale are interbedded with the sandstone. A poorly exposed, thin zone containing float of well rounded, dark-gray chert pebbles was noted near the easternmost exposure of the Laramie Formation. Morgan and others (2003) noted coal beds in the Laramie Formation in the Cascade quadrangle a few miles south of the outcrops described here.

Kfh **Fox Hills Sandstone (Upper Cretaceous) —** Shown only on cross sections. Refer to the Cascade quadrangle (Morgan and others, 2003) for description. Thickness determined from the Higby No. 1 petroleum exploration well in the Larkspur quadrangle, approximately 1.3 miles north of the Palmer Lake quadrangle boundary.

Kp **Pierre Shale (Upper Cretaceous) —** Shown only on cross sections. Refer to the Cascade quadrangle (Morgan and others, 2003) for description. Thickness determined from the Higby No. 1 petroleum exploration well in the Larkspur quadrangle, approximately 1.3 miles north of the Palmer Lake quadrangle boundary.

Kn **Niobrara Formation (Upper Cretaceous) —** The Niobrara Formation in the Palmer Lake quadrangle is exposed only in thin, fault-bounded lenses in the northwestern part of the Air Force Academy grounds. Exposures consist of white and gray shaly chalk and marl; thinly bedded, fissile, yellowish-brown to medium brownish-gray calcareous shale; and a single (?) four- to eight-foot-thick layer of light- to medium-brownish-gray, dense, thin-bedded, competent, fossiliferous limestone. The competent limestone bed is fine to medium crystalline, resistant to erosion, and underlies the crests of small hogbacks. Small shell fragments, planktonic foraminifer tests, and crystalline calcite prisms are visible in thin sections and are suspended in a finely crystalline matrix that reportedly consists principally of disaggregated coccolith fragments (Longman and others, 1998). Some thin sections of the limestone show that at least some beds are composed mostly of medium-grained crystalline calcite. Large (1-4 in.) fossil *Inoceramus* shells are common. The Niobrara Formation was deposited in a quiet marine environment during a period of major marine transgression and high sea level in Coniacian and Santonian time (Longman and others, 1998).

Exposed Niobrara beds are overturned and dip moderately to steeply west. We tentatively interpret this faulted lens to be an incomplete exposure of the Smoky Hill Shale Member of the Niobrara Formation, which contains limestone beds near the base (Thorson and others, 2001). However, Varnes and Scott (1967) interpreted that both the Fort Hayes Limestone Member and the Smoky Hills Shale Member are present in this structurally complex area. The single bed of competent, fossiliferous limestone described above is similar in character (though much thinner) to the Fort Hayes Member in nearby areas. The total thickness of the Niobrara Formation is approximately 450 feet in the Colorado Springs region (Carroll and Crawford, 2000). The maximum exposed thickness of the Niobrara Formation in the Palmer Lake quadrangle is between 250-300 feet.

Kc **Carlile Shale, including Codell Sandstone Member (Upper Cretaceous) —** The Carlile Shale, of which the Codell Sandstone is here most visibly represented, is exposed in a narrow, fault-bounded lens in the northwestern part of the Air Force Academy grounds. The Codell Sandstone is white, very light-gray, and light-yellow-brown, highly calcareous, medium-grained, well-sorted sandstone. Quartz sand grains are moderately well rounded. The unit forms a low hogback just west of another hogback formed by limestone of the Niobrara Formation. It weathers into slightly rounded pebble- and cobble-size fragments before disaggregating to form light-gray sandy soil. The shale units in the Carlile Shale are very poorly exposed in the quadrangle. Small exposures in a roadcut consist of soft, thin-bedded, laminated, dark-gray to black shale that easily weathers to platy chips. These dark shales contain several bentonite layers. In the Cascade quadrangle (Morgan and others, 2003) and the Pikeview quadrangle (Thorson and others, 2001), dark shales are commonly interbedded with brown siltstone, sandstone, and minor limestone. Where fully exposed, the total thickness of the Carlile Shale (including the Codell Sandstone Member) is approximately 220 feet in this region (Keller and others, 2005; Morgan and others, 2003).

Kcgg **Graneros Shale, Greenhorn Limestone, and Carlile Shale, undivided (Upper Cretaceous) —** Shown only on cross sections. Refer to the Cascade quadrangle (Morgan and others, 2003) and Pikeview quadrangle (Thorson and others, 2001) for descriptions.

Kdp **Dakota Sandstone and Purgatoire Formation, undivided (Lower Cretaceous) —** Shown only on cross sections. Refer to the Cascade quadrangle (Morgan and others, 2003) for descriptions.

Jmr **Morrison Formation and Ralston Creek Formation, undivided (Upper Jurassic) —** Shown only on cross sections. Refer to the Cascade quadrangle (Morgan and others, 2003) for descriptions.

ꞦIPr **Triassic, Permian, and Pennsylvanian rocks, undivided —** Shown only on cross sections. Includes Lykins Formation (Lower Triassic? and Upper Permian), Lyons Sandstone (Permian), and Fountain Formation (Lower Permian and Pennsylvanian). Refer to the Cascade quadrangle (Morgan and others, 2003) for descriptions. Varnes and Scott (1967) mapped some of these formations west of our mapped exposures of the Niobrara Formation and Carlile Shale in the structurally complex area in the far northwestern part of the Air Force Academy grounds. Our mapping does not confirm the presence of these rocks in that area.

Om **Manitou Limestone (Lower Ordovician)** — The Manitou Limestone is exposed in a small, fault-bounded block directly west of the Rampart Range Fault and about ¾ mile west of Deadmans Lake in the northwestern part of the Air Force Academy grounds. The unit dips east from 29° to 57° (steepening eastward), forming a light-grayish-brown flatiron visible for several miles around. The Manitou Limestone here consists of resistant, light-gray to brownish-gray limestone beds of marine origin. The unit is thin to medium bedded and commonly contains wavy bedding planes. Weathered surfaces are pinkish tan, reddish gray, and yellowish gray. Trace fossils (burrows) are locally abundant. The exposed thickness of the formation is 130 to 140 feet. The total thickness of the formation, where it is better exposed in the Cascade and Manitou Springs quadrangles, is about 185 feet (Keller and others, 2005; Morgan and others, 2003). The upper 45 feet of the formation is largely dolomitic, but this upper part has here been stripped by erosion. The Manitou Limestone rests unconformably over the Cambrian-age Sawatch Sandstone (Myrow and others, 2003). Our limited bedding measurements indicate that the degree of angular discordance is probably very small here. However, flexure of the beds due to local faulting, combined with a lack of good exposures, makes accurate assessment of the degree of angularity problematic. In southeastern Colorado, only the upper part of the Manitou Limestone (also called Manitou Formation) is preserved above the regional unconformity developed during the *Rossodus manitouensis* conodont zone in Early Ordovician time (Myrow and others, 2003).

Ꞓs **Sawatch Sandstone (Upper Cambrian)** — The Sawatch Sandstone rests on Pikes Peak Granite in a small, fault-bounded block directly west of the concealed Rampart Range Fault and about ¾-mile west of Deadmans Lake in the northwestern part of the Air Force Academy grounds. The unit dips east and underlies the Manitou Limestone. On the basis of limited exposures, the Sawatch Sandstone here consists of dark-purple-gray and dark-green, well-indurated, fine-grained, thin-bedded, dolomitic sandstone. The unit is 40 to 50 feet thick. Green coloration of many of the beds is due to the presence of glauconite, which indicates this is the middle member of the Sawatch Sandstone (Myrow and others, 1999). The middle member was interpreted by Myrow (1998) to have been deposited subaqueously as low-amplitude, long-wavelength tidal dunes in a transgressive environment. The basal member of the formation, which further south consists of a 14-foot-thick zone of white to light-gray-green, arkosic and conglomeratic sandstone (Myrow, 1998; Keller and others, 2005; Morgan and others, 2003), and the contact with underlying granite, are obscured here by surficial deposits. A northwest-trending fault truncates the Sawatch Sandstone and juxtaposes Manitou Limestone with Pikes Peak Granite at the southern end of the lower Paleozoic exposure area in the Palmer Lake quadrangle.

A clastic dike, tentatively identified as Sawatch Sandstone, cuts highly fractured Pikes Peak Granite in the hanging wall of the Rampart Range Fault on the north bank of Monument Creek at the mouth of Limbaugh Canyon. The sandstone in the dike is purplish and reddish gray to yellowish brown, fine to medium grained, and calcareous. It consists mainly of rounded to subangular quartz grains cemented in silica, carbonate, and hematite. The dike also contains angular inclusions of Pikes Peak Granite and broken feldspar crystals derived from the granite. A few specks of green glauconite(?) were observed using a hand lens. Limited exposures indicate that the dike trends approximately N25E. Similar dikes are known from other locations in the southeastern Front Range, and the timing of emplacement is poorly known (Harms,1965; Keller and others, 2005).

Ypeg **Pegmatite (Mesoproterozoic)** — Very coarse grained pink and white veins, lenses, and pods consisting chiefly of feldspar and quartz. Most pegmatites in the quadrangle are small, less than 5 feet thick and 50 feet in length, and thus were not mapped separately. Two larger pegmatites, both which have been mined in the past for feldspar and/or quartz, were mapped. One of these is exposed in an open cut just west of road FR 313 in the south-central part of the quadrangle. It trends approximately N15°W, is approximately 40 feet wide in the widest part, and is at least 60 feet in length. It consists of pink microcline feldspar (±75 percent), milky and clear-gray quartz (±17 percent), white plagioclase feldspar (±5 percent), biotite (±1-2 percent), and zinnwaldite (< 1 percent). Zinnwaldite (a lithium-bearing mica), identified by Foord and Martin (1979) as a common constituent of pegmatites in the Pikes Peak batholith, occurs here as long, bladed, tapering, shiny greenish- to bronze-colored crystals. "Graphic granite" textured intergrowth of feldspar and quartz is common. The other large pegmatite is along the far northwestern quadrangle boundary adjacent to Road 324. This pegmatite, up to 50 feet wide, was substantially mined along an open cut approximately 400 feet long, most of which is in the adjacent Mount Deception quadrangle. This pegmatite trends approximately N25°W and consists of pink feldspar and quartz. The pegmatite is roughly zoned, with localized and distinct quartz-rich and feldspar-rich areas.

Ywp **Windy Point Granite (Mesoproterozoic)** — Windy Point Granite (fig. 7) is pinkish-gray to pinkish-tan, fine- to medium-grained granite and quartz monzonite. The unit weathers to reddish-tan or buff. It is blocky weathered compared to the rounded weathered outcrops of the coarse-grained Pikes Peak Granite. Windy Point Granite is usually porphyritic. Microcline phenocrysts up to 0.75 inches across commonly stand out in relief giving weathered surfaces a "knobby" appearance. Quartz phenocrysts may be present as well but are not as large as microcline phenocrysts. Dikes and lenses of Windy Point Granite are present only in the southeastern part of the quadrangle in the vicinity of the large, north-south-trending syenite body (Ysy). Typically, Windy Point Granite is more resistant to weathering than the enclosing coarse-grained granite or syenite and forms rocky caps of small, linear to curvilinear ridges that reflect the geometry of the lens-shaped and arcuate plutons that intrude the Pikes Peak Granite and syenite. The small plutons of Windy Point Granite are spatially related to the larger syenite pluton. Windy Point Granite is geochemically similar to Pikes Peak Granite and is thought to be a late-stage, rapidly cooled variant of Pikes Peak Granite (Wobus, 1976). On the basis of thin section evaluation (Wobus, 1976), the principle minerals composing the Windy Point Granite in the Rampart Range are quartz (40 percent), alkali feldspar (mainly microcline; 29 percent), plagioclase (albite-oligoclase; 27 percent), and biotite (6 percent). Trace minerals include zircon, apatite, fluorite, and muscovite. Microcline is partly perthitic. Biotite commonly occurs in rounded clusters. Quartz usually occurs as individual grains rather than as clusters of grains. Major and trace element analyses of Windy Point-type granites were reported by Smith and others (1999b). Most masses of Windy Point Granite in the quadrangle appear to dip moderately west, subparallel to weak primary igneous foliation or jointing, and similar to the larger syenite mass. Finley

(1916) originated the name Windy Point granite for plutons exposed on Pikes Peak; the unit was referred to as "porphyritic granite" by Gross and Heinrich (1965). Wobus (1976) applied the formal name Windy Point Granite to finer-grained, locally porphyritic potassic granites that intrude the dominant coarse-grained Pikes Peak Granite in large areas of the batholith.

Figure 7. Photograph of Windy Point Granite exposed along an old roadcut in the NW ¼ of sec. 8, T. 12 S., R. 67 W., Palmer Lake quadrangle.

Ysy **Syenite (Mesoproterozoic)** — Syenite forms an elongated, north-south-trending pluton in the southeastern part of the Palmer Lake quadrangle. Syenite is medium reddish pink to light pinkish gray, coarse grained, and equigranular (fig. 8). The main pluton forms a long, steep-sided ridge with rounded knolls along the crest. Syenite weathers to form medium-sized, rounded bouldery outcrops and tends to be slightly more resistant to erosion than adjacent Pikes Peak Granite, but slightly less resistant than the finer-grained Windy Point granite. On the basis of thin sections (Wobus, 1976) and our observations, unit Ysy consists of 80-90 percent alkali feldspar (microcline) crystals 0.5 to 1.5 inches across, plagioclase (albite-oligoclase; 10-15 percent), quartz (0-10 percent), and pyroxene (<0.5 to 8 percent). Quartz usually constitutes less than 1 percent of the syenite, but locally syenite may contain up to 10 percent quartz near contacts with Pikes Peak Granite or Windy Point Granite. At places where quartz constitutes more than 5 percent of the rock mass, it is by definition quartz syenite rather than syenite (Streckeisen, 1974). Wobus (1976) provided a major-element geochemical analysis of a sample of syenite from the Palmer Lake quadrangle.

Syenite locally displays what we interpret to be faint primary igneous flow foliation. The foliation is manifested as joint-like planes of weakness parallel to the long axis of the pluton that dip moderately west. We interpret that the syenite mass dips west parallel to this primary foliation or jointing.

Figure 8. Photograph showing equigranular texture of syenite (unit Ysy). Note the lack of quartz and mafic minerals. Primary igneous foliation is not discernible in the photo. Syenite is exposed in the southeast part of Palmer Lake quadrangle.

Ypp **Pikes Peak Granite (Mesoproterozoic)** — Pikes Peak Granite is the most abundant of the intrusive rock types in the Palmer Lake quadrangle. This hornblende-bearing biotite granite is the main constituent of the potassic series of intrusives that constitute more than 90 percent of the batholith as a whole (Wobus, 1976; Smith and others, 1999b). Pikes Peak Granite is pink to light gray, coarse grained, and usually equigranular. It weathers to form rounded, bouldery outcrops (fig. 9).

Figure 9. Photograph of Pikes Peak Granite in the northern part of the Palmer Lake quadrangle. Note the round-weathered corestone at left and the smoothly eroded domes in the background.

Weathering of Pikes Peak Granite usually produces deposits of grüs (loose, disaggregated mass of constituent minerals). Grüs is best developed on north-facing slopes and can accumulate to thicknesses as much as 150 feet (Blair, 1976). Grüs develops first along joints in the granite. More resistant rock between joints may remain intact as rounded "corestones" (Blair, 1976). A corestone of Pikes Peak Granite that is rapidly disintegrating to grüs, and containing a more resistant aplite dike, is shown in fig. 10. Note the resistant cap, a zone of consistent thickness (8-12 inches) having a slightly darker color than the underlying material. These caps are more resistant to erosion than the interiors of the corestones and commonly form flat to slightly curved caps on eroding boulders; these caps are usually tilted subparallel to the slopes on which the corestones are eroding. The capped corestones occasionally take the form of hoodoos. The caps are casehardened surfaces slightly enriched in secondary silica and iron oxides, which were probably deposited by surface water slightly enriched in mineral constituents seeping into the granite surface and are the effect of repeated wetting and drying (Blair, 1976).

Highly fractured areas of Pikes Peak Granite, particularly along the Rampart Range Fault, commonly are deep red in color due to hematite staining and are less resistant to weathering. Weathering in these fractured areas produces angular rock fragments rather than grüs. Gross and Heinrich (1965) described the petrology of the Pikes Peak Granite in detail. The constituent minerals of Pikes Peak Granite are perthitic microcline (35-50 percent), quartz (20-35 percent), plagioclase (oligoclase; 10-20 percent), biotite (2-7 percent), and hornblende (<0.5 – 2 percent). Accessory minerals include zircon, apatite, magnetite, and fluorite, plus rare allanite and bastnaesite. Major and trace element analyses of the Pikes Peak Granite were reported by Smith and others (1999b). Fine- to medium-grained aplite dikes (fig. 10), typically 0.5 to 2.0 feet in width, are widely scattered in the Pikes Peak Granite but were not been mapped separately. Small pegmatite dikes and quartz veins are locally common and also were not mapped separately. A small area of schlieren granite (compositionally layered texture due to variation in mafic contact) is located a short distance upstream from the mouth of Limbaugh Canyon on Monument Creek. A foliation symbol on the geologic map (plate 1) indicates its location.

Figure 10. Corestone of Pikes Peak Granite with a small aplite dike. This corestone is in the final stages of grüsification and decomposition. Note the slightly more resistant cap, and the presence of grüs near the base of the outcrop.

Geologic time divisions used in this report are shown in figure 11.

MESOPROTEROZOIC IGNEOUS ROCKS OF THE PIKES PEAK BATHOLITH

Late Mesoproterozoic granitic rocks of the Pikes Peak batholith are the oldest rocks exposed in the Palmer Lake quadrangle. These form nearly all of the bedrock west of the Rampart Range Fault. The Pikes Peak batholith is exposed over an area of 1,200 mi^2 in the southern Front Range (Tweto, 1987). Numerous studies have been conducted on the batholith, which was emplaced 1090 to 1020 Ma (Aldrich and others, 1957; Bickford and others, 1989; Unruh and others, 1995; Smith and others, 1999a). Cross (1894) first mapped the geology of the Pikes Peak region and in 1894 applied the formal name Pikes Peak Granite (Ypp) to the most common rock type in the batholith. Hutchinson (1972, 1976) studied the granite tectonics and modes of intrusion of the batholith and showed that the batholith is composite in nature. Barker and others (1975) produced a comprehensive petrologic and geochemical description of the rocks that comprise the batholith and noted that the batholith is composed of granites that have two distinct chemical trends, or series: the dominant potassic series, and a sodic series. Wobus (1976) provided petrologic and major-element chemical data for smaller plutons of both the potassic and sodic series.

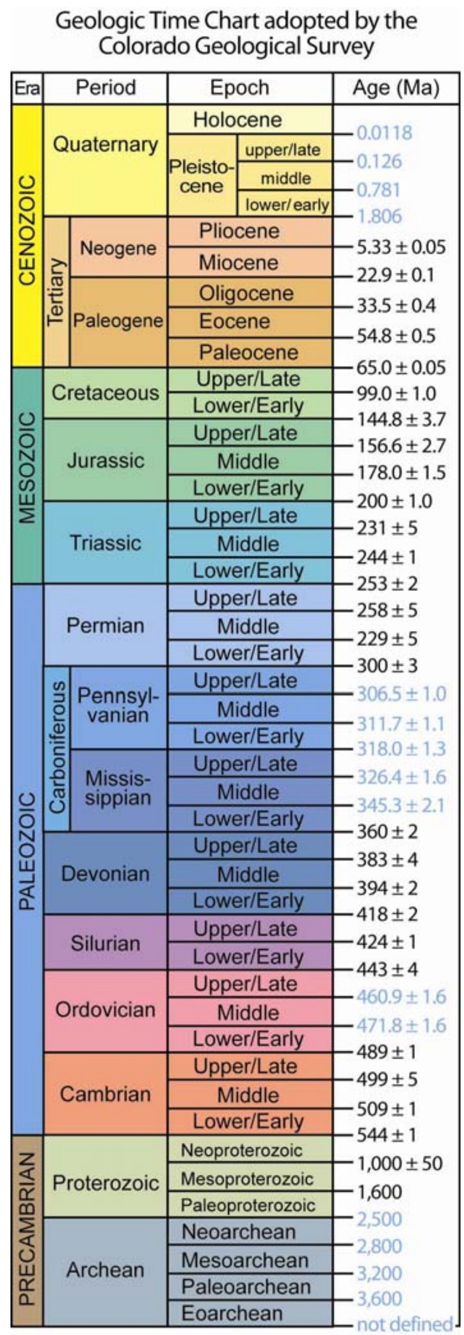

Figure 11. Geologic time chart used for this report. Numerical ages shown in black are from the Geological Survey of Canada (Okulitch, 2002); ages shown in blue are from the International Commission on Stratigraphy (2005).

Only rocks of the potassic series are represented in the Palmer Lake quadrangles. Pikes Peak Granite (Ypp) is the most voluminous rock type in the Pikes Peak batholith. In the southeastern part of the Palmer Lake quadrangle, an elongate mass of syenite (Ysy) and several smaller bodies of the late-phase Windy Point Granite (Ywp) are exposed. Smith and others (1999b) studied the petrology and geochemistry of late-stage intrusions of the batholith and showed that both fractionation of mantle-derived magmas and melting of preexisting crustal rocks (anatexis) were involved in the petrogenesis of the batholith. The potassic series granites, including the Pikes Peak Granite, are interpreted to be derived from crustal anatexis. Smith and others (1999a) provide a review of the chemistry and genesis of the Pikes Peak batholith and note that the batholith is an example of A-type granitic magmatism. Pegmatites and veins in the Pikes Peak batholith have locally produced an abundance of specimen-quality mineral samples. Foord and Martin (1979) and Muntyan and Muntyan (1985), among others, describe the mineralogy of the pegmatites in the Pikes Peak batholith.

LOWER PALEOZOIC MARINE SEDIMENTARY ROCKS

A 140- to 180-feet-thick veneer of Lower Paleozoic strata rests unconformably on Pikes Peak Granite in a fault-bounded block northwest of the main campus of the U.S. Air Force Academy. East-dipping Upper Cambrian Sawatch Sandstone (Ꞓs) and Upper Cambrian to Lower Ordovician Manitou Limestone (Om) form the light-gray flatiron ¾-mile west of Deadmans Lake. Myrow and others (2003) describe the Cambrian and Ordovician strata of Colorado and provide new insights into the paleogeography of the Rocky Mountain region during that time. In eastern and southern Colorado (including the Palmer Lake quadrangle), the lower part of the Manitou Limestone and upper part of the Sawatch Sandstone were removed by erosion along an unconformity developed during the *Rossodus manitouensis* conodont zone. Thus, only the older, lower part of the Sawatch Sandstone and the younger, upper part of the Manitou Limestone are present in the Palmer Lake quadrangle and surrounding areas. This unconformity is the result of an uplift, informally named the mid-Rossodus uplift (Myrow and others, 2003), centered in southern Colorado in Early Ordovician time. A thicker and more complete section of Paleozoic strata is exposed south of the Palmer Lake quadrangle in the Cascade quadrangle (Morgan and others, 2003) and in the Manitou Springs quadrangle (Keller and others, 2005).

UPPER CRETACEOUS MARINE SEDIMENTARY ROCKS

Carbonate and siliclastic rocks deposited in the Western Interior Seaway during Late Cretaceous time are exposed in a small, complexly faulted area in the gunnery range in the northwest corner of the U.S. Air Force Academy grounds (sec. 5, T. 12 N., R. 67 W.). Steeply to moderately dipping, locally overturned beds of the Niobrara Formation, the Codell Sandstone, and shales of the Benton Group are exposed in at least two faulted slivers within the Rampart Range fault zone. East-dipping sandstone and minor shale of the Laramie Formation are exposed in a narrow strip east of these faulted slivers of older Upper Cretaceous rocks and also directly west of the faulted slivers in what we tentatively interpret as a small graben within the Rampart Range fault zone. Access in this structurally complex area is limited because of weapons practice at the gunnery range located less than one mile east of the outcrop area. Other Mesozoic and Upper Paleozoic formations including the Dakota Sandstone, Lykins Formation, Lyons Sandstone, and Fountain Formation were mapped in this part of the Air Force Academy previously (Varnes and

Scott, 1967), but our mapping did not confirm surface exposures of these formations. All of these formations and other Upper Cretaceous rocks including the Pierre Shale and Fox Hills Sandstone are exposed in the Cascade quadrangle to the south (Morgan and others, 2003).

UPPER CRETACEOUS AND TERTIARY SYNOROGENIC CLASTIC ROCKS

The Dawson Formation — The bedrock in most of the eastern part of the Palmer Lake quadrangle is the Cretaceous and Tertiary age Dawson Formation (TKda). Younger bedrock units including the conglomerate of Larkspur Butte, the Wall Mountain Tuff, and the Castle Rock Conglomerate, while present in adjacent areas for example, the Black Forest, Greenland, Castle Rock South, and Castle Rock North quadrangles, are not present in this quadrangle, where they may have been removed by erosion.

The sedimentary rocks lying above the Laramie Formation were first called Dawson “arkose” (with a lower case “a”) by Richardson (1912) from a type locality on Dawson Butte near the town of Castle Rock, about 10 miles north of the Palmer Lake quadrangle. Richardson (1915, Fig. 3) showed the Dawson “arkose” of the Castle Rock area as equivalent to, and interfingering with, the Arapahoe and Denver Formations of the Denver area (fig. 12). Finlay (1916) recognized that the Dawson “arkose” extended into the Colorado Springs area and contained an andesitic sandstone unit at the base. Varnes and Scott (1967) used the name Dawson Arkose (upper case “A”) and recognized that there are two “beds of andesitic material” in the area south and east of the U.S. Air Force Academy. Scott and Wobus (1973) changed the name to Dawson Formation, in recognition that the unit was not entirely composed of arkose; they mapped a lower part (andesitic) and upper part of the Dawson Formation. In the Pikeview quadrangle, Thorson and others (2001) mapped three informal members in the upper part of the Dawson Formation that Scott and Wobus (1973) described but did not map separately. In subsequent studies (Thorson, 2003a [Black Forest], 2003b [Greenland], 2004a [Castle Rock South], 2004b [Cherry Valley School], 2005a [Castle Rock North], 2005b [east half Larkspur]; Thorson and Madole, 2002 [Monument], Madole and Thorson, 2002 [Elsmere], Morgan and others, 2004 [Dawson Butte]), six facies units have been recognized as informal members of the upper part of the Dawson Formation. Facies units one, three, four and five are present in the Palmer Lake quadrangle. The nomenclature used in our description for the Dawson Formation follows that of Scott and Wobus (1973) and Trimble and Machette (1979a) in referring to Dawson Formation rather than Dawson Arkose. The use of the symbol “TKda” for the upper part of the Dawson Formation follows the usage of Trimble and Machette (1979a).

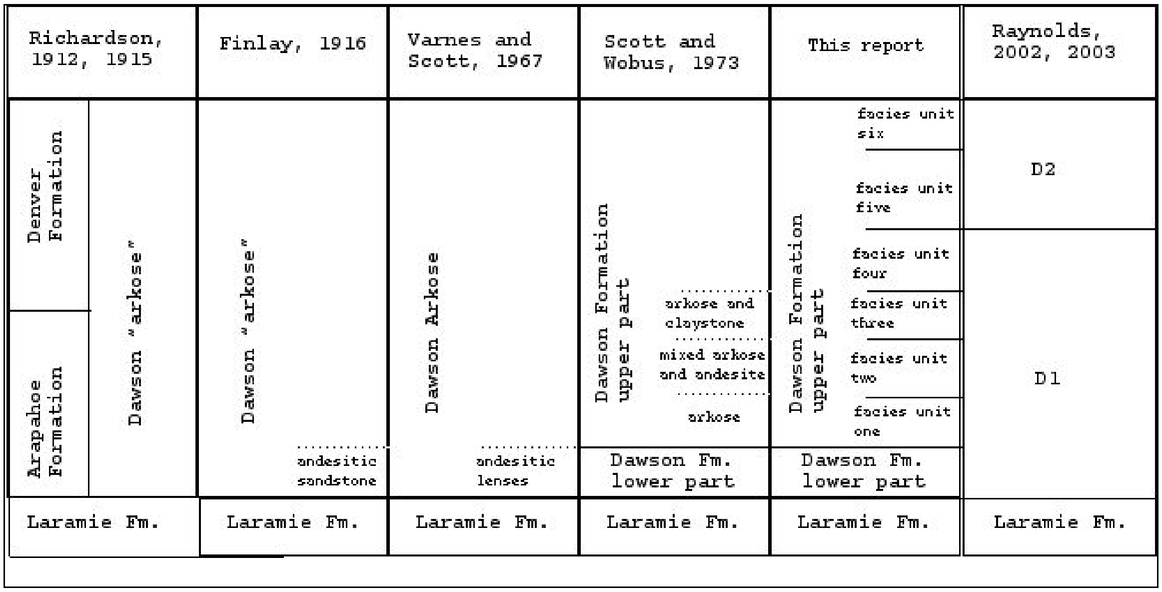

Figure 12. Nomenclature diagram for subdivisions of the Dawson Formation as used in various publications pertaining to the Colorado Springs area. The subdivisions of the Dawson Formation used in this report have been developed in a series of Colorado Geological Survey Open File Reports; for complete descriptions see Thorson, 2003a, 2003b, 2004b, 2005a, 2005b; Thorson and others, 2001; Madole and Thorson, 2002; and Thorson and Madole, 2002. The subdivisions used by Raynolds (2002, 2003) are summarized in Johnson and others (2002, 2003).

Facies of the upper Dawson Formation — The upper part of the Dawson Formation consists of six facies units between Denver and Colorado Springs: facies unit one through facies unit six (TKda1 – TKda6). Figure 13 diagrammatically shows the regional relationships between these units. Facies unit one occurs in part as a very thick "basin edge" deposit close to the mountain front on the western edge of the basin in the Pikeview, Monument, and Palmer Lake quadrangles. Facies unit one also occurs as a coarse basal unit of the upper Dawson, beneath finer-grained facies that crop out from the Pikeview quadrangle southeastward into the Elsmere quadrangle (Madole and Thorson, 2002). Finer-grained basinal facies units two and three interfinger with and overlie the coarser mountain front and basal facies unit one. Facies unit two does not crop out in the Palmer Lake quadrangle. In the Palmer Lake quadrangle and the adjacent Monument quadrangle, facies units four and five, dominated by light-colored arkoses, were deposited over the top of the finer-grained facies unit three. Facies unit six is not present in the Palmer Lake quadrangle. Contacts between facies units within the basin are both gradational and interfingering.

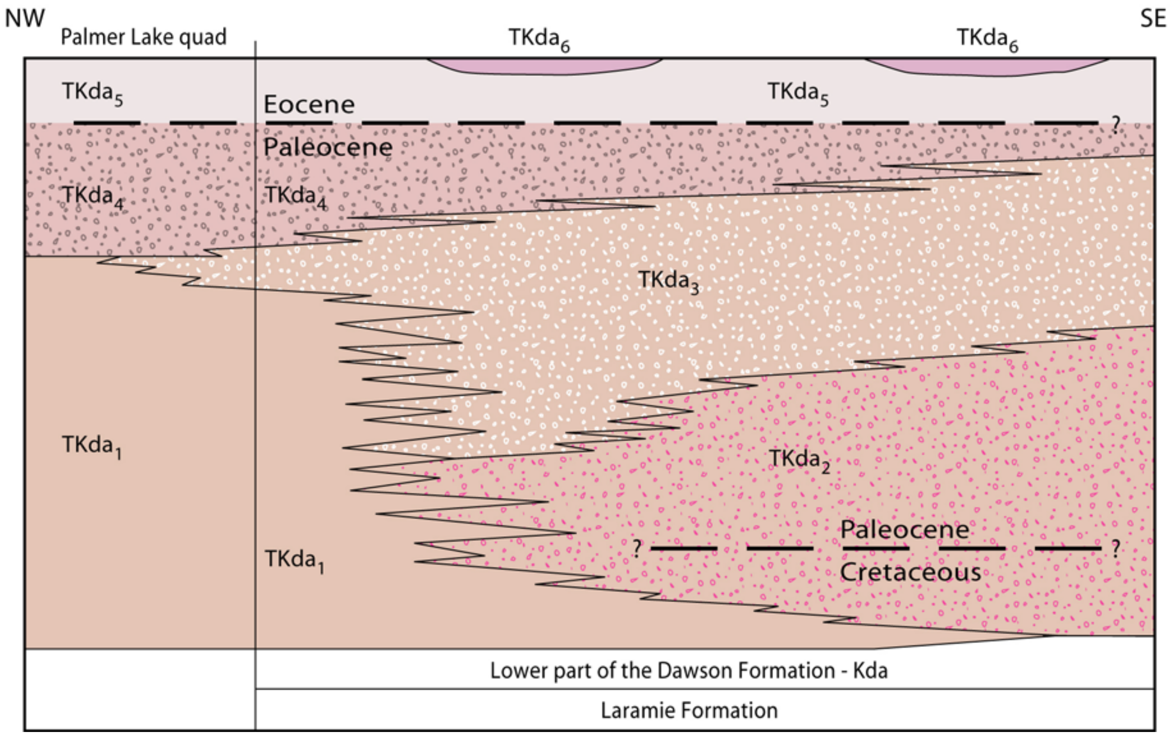

Figure 13. Diagrammatic sketch showing the regional relationships between the facies units of the upper part of the Dawson Formation in the Colorado Springs area, and showing the relationship of the strata in the Palmer Lake quadrangle to the facies units in more basinal locations. Heavy dashed lines indicate the approximate stratigraphic locations of geologic time lines.

The relationship of the Dawson Formation subdivisions of the Colorado Springs area to the stratigraphy used in the Denver area has been uncertain for some time. Trimble and Machette (1979b) summarized the current usage of Arapahoe, Denver, and Dawson Formations (in ascending order) for the greater Denver area (fig. 14). The Arapahoe and Dawson Formations consist of arkosic sandstone, siltstone, claystone, and minor amounts of conglomerate. Where this arkosic and conglomeratic lithology underlies the andesitic Denver Formation it is called the Arapahoe Formation. The Denver Formation consists of claystone, siltstone, sandstone, and conglomerate composed primarily of altered andesitic volcanic debris. The Denver Formation has been projected to pinch out to the south and east (Bryant and others, 1981). Beyond the pinch out, all of the strata equivalent to the Arapahoe and Denver Formation are included in the Dawson Formation.

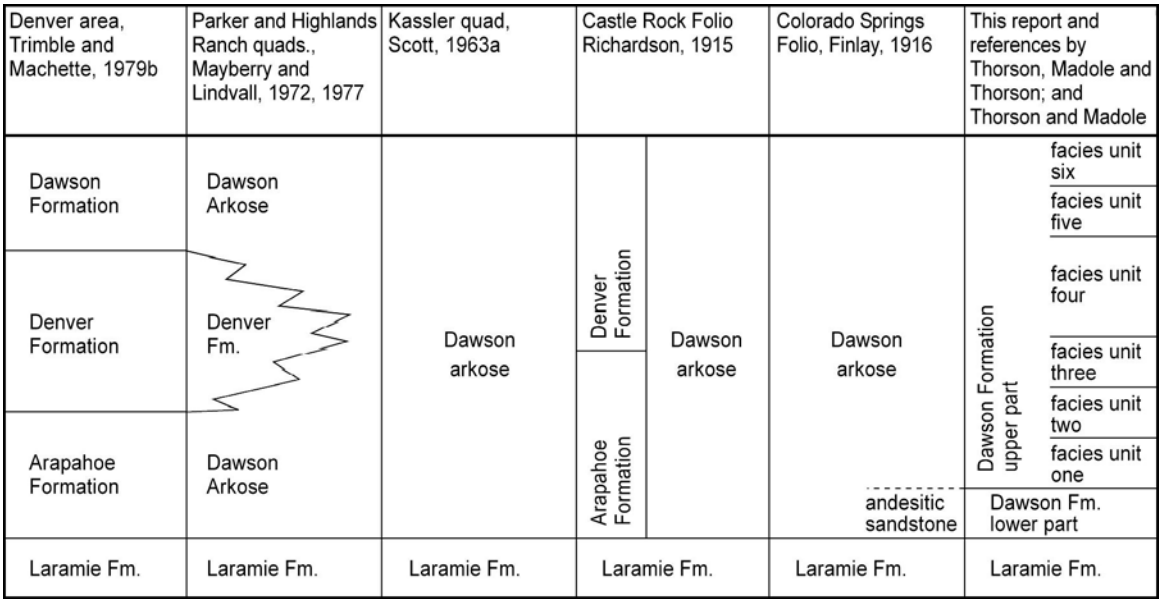

Figure 14. Relationship between the subdivisions of the Dawson Formation used in this report and the stratigraphic nomenclature of the Denver Area.

The interfingering of the Denver Formation with the Dawson Formation, and the pinch out of the Denver Formation to the southeast, has been mapped along the southern edge of the Denver metropolitan area. Scott (1962, p. L19-L20) described apparent interfingering of the Denver Formation with the Dawson "arkose" in the Littleton quadrangle and concluded that "southward they (andesitic beds) probably dwindle to a thin tongue in the Dawson arkose". In the Kassler quadrangle Scott (1963b) retained the usage Dawson "arkose" for the whole unit and did not find a mappable unit dominated by andesitic debris. Maberry and Lindvall (1972, 1977) mapped an upper tongue of Denver Formation that interfingers with the Dawson Arkose in the Parker and Highlands Ranch quadrangles. Trimble and Machette (1979b) summarized this relationship and changed the formation name from Dawson Arkose to Dawson Formation.

However, it is common usage in the Colorado Springs area to map the andesite-bearing facies unit, here mapped as upper Dawson Formation facies unit two, as the Denver Formation (John Himmelreich, Jr., personal communication, 2000). This correlation has largely come about through the use of the Denver-area formation names (Arapahoe, Denver, and Dawson) for regional aquifer units that have been extended throughout the hydrologic Denver Basin (see for example, Robson, 1987). The extension of the Denver-area formation nomenclature throughout the Denver Basin was accomplished largely by correlating geophysical log signatures of hydrologic units in water and oil wells. Unfortunately, the hydrologic units do not correlate precisely with the mappable geologic units exposed at the surface (George VanSlyke, personal communication, 2000). The geophysical logs used for this correlation can separate porous and permeable sandstones and conglomerates from "tight" shales and claystones, but they can not reveal the lithologies of the sandstones and pebble conglomerates. The geologic units mapped at the surface are based on lithological criteria, largely the presence or absence of andesitic debris, a distinction which can not be made from geophysical logs from wells.

However, current directions and facies relationships of facies unit two in the Elsmere quadrangle in southeastern Colorado Springs (see fig. 3 for location) suggest that the source for the sediments of this unit was south and west of the region (Madole and Thorson, 2002). It is likely that the andesitic conglomerates of the Denver Formation, which are in part coarser than those of facies unit two, were transported from a separate source that was far to the north of the source for facies unit two. Crifasi (1992) has analyzed the thicknesses and sand/shale ratios of the hydrologic aquifers of the Denver Basin and also argues for multiple sediment distribution systems for each of the stratigraphic units. In the Monument and Palmer Lake quadrangles facies units three and four contain a large component of light-greenish-gray montmorillonitic claystones and siltstones. These units from the Monument and Palmer Lake quadrangles have been correlated with the Denver Formation by mapping correlative strata through the Larkspur, Dawson Butte, and Castle Rock North quadrangles (see fig. 3 for quadrangle locations). This mapping (Thorson, 2005a, 2005b; and Morgan and others, 2004) indicates that Dawson Formation facies unit four of the Monument quadrangle becomes finer grained and richer in montmorillonitic clays to the north, while the Denver Formation becomes finer grained and less rich in montmorillonitic clay to the south. We therefore interpret that Dawson Formation facies units three and four of the Palmer Lake and Monument quadrangles and facies unit four of the Larkspur and Dawson Butte quadrangles correlate with the Denver Formation of the Denver stratigraphy.

Age of the upper Dawson Formation — The upper part of the Dawson Formation spans the Cretaceous-Tertiary (K-T) boundary, but the exact location of the time boundary near the western edge of the basin has not been located. Kluth and Nelson (1988) reconfirmed the Late Cretaceous (late Maastrichian) age for the upper part of the Dawson Formation on the U.S. Air Force Academy. In the Elsmere quadrangle (see fig. 3 for location) the K-T boundary has been located approximately 370 feet above the base of the upper part of the Dawson Formation (Benson, 1998; Benson and Johnson, 1998; Johnson and Raynolds, 2001; Madole and Thorson, 2002). The fossil leaf locality known as Scotty's Palm (DMNH-1204, NE¼ SW¼ sec. 12, T. 12 S., R. 67 W.) is Paleocene in age and located about 600 feet above the base of the upper part of the Dawson Formation in the Monument quadrangle (Johnson, 2001; Johnson and others, 2003). Therefore much of the upper part of the Dawson in the Palmer Lake quadrangle is interpreted to be Paleocene in age. A well-developed paleosol, found at several localities in the Monument quadrangle, extends into the Palmer Lake quadrangle. This horizon may be a regional paleosol traced around the basin by Soister and Tschudy (1978) and proposed to mark the Paleocene-Eocene boundary. Raynolds and Johnson (2003, fig. 3, p. 176) have interpreted the depositional hiatus represented by the Denver Basin regional paleosol to be 8 to 9 million years. This paleosol has been used as the boundary between facies units four and five in the Palmer Lake and Monument quadrangles. Such an age distinction remains to be confirmed in the Palmer Lake area because there are multiple paleosol horizons near the mountain front edge of the basin (Thorson and Madole, 2002a, Thorson 2003, Morgan and others, 2004).

TERTIARY AND QUATERNARY SURFICIAL DEPOSITS

Dissected remnants of Tertiary gravels cover the gently rolling topography of the Rampart erosion surface (fig. 15) that was cut into granitic bedrock probably during the late Eocene and Miocene (Steven and others, 1997). Within the mapped area, the gravel deposits contain rounded fragments of metasedimentary Precambrian rocks possibly derived from areas to the south, and volcanic rocks probably derived from the latest Eocene-early Oligocene Thirty-nine Mile volcanic field about 25 miles west of the mapped area (Scott and Wobus, 1973; Mertzman and others, 1994; Steven and others, 1997). The Rampart erosion surface is dissected by a Quaternary network of creeks that often follow fractures, joints, and faults in the Mesoproterozoic crystalline rocks. The creeks contain a thin deposit of alluvium mixed with colluvium and may also contain local debris flow deposits.

Figure 15. The nearly flat top of the Rampart Range, as viewed from Balanced Rock Road in the Palmer Lake quadrangle, reflects the late Eocene and Miocene Rampart erosion surface. Pikes Peak rises above the erosion surface in the left distance.

Six levels of Pleistocene to Holocene alluvial deposits are present within the Palmer Lake quadrangle. These deposits were formed by predominantly fluvial processes during the Pleistocene glaciations when large precipitation events produced high discharge rates that allowed the deposition of voluminous amounts of coarse sediment (Madole, personal communication, 2005). These discharge events were not directly related to glaciers but were associated with climatic conditions (i.e. high precipitation) that were favorable for producing glaciers. The Pleistocene alluvial deposits were deposited in paleochannels that once emptied onto the Piedmont; they are now higher in the landscape due to topographic inversion (Wayne and others, 1991).

Near the mountain front, the alluvial deposits are clast-supported boulder gravel of granitic clasts from the Pikes Peak batholith and lesser amounts of volcanic, metamorphic, and sedimentary clasts. The amount of boulder- and cobble-sized sediment is strongly dependent on whether the stream headed in the mountains or on the Piedmont (Wayne and others, 1991). Late Pleistocene and Holocene valley-fill alluvium deposited by creeks on the Piedmont contain far fewer boulders and more sand and silt than the older alluvial deposits that headed in mountainous terrain. These valley-fill deposits may also form low terraces above modern stream channels.

Other Pleistocene and Holocene deposits include colluvium, sheetwash, and landslides. Colluvium deposits along the mountain front are of two different relative ages based upon their current relative height in the landscape and distance from the present range-front escarpment. At several places along the base of the Rampart Range, recession of the mountain front westward has left the older colluvium (unit Qc_2) and early Pleistocene alluvium stranded on flatiron-like ridges. The more resistant boulder gravels help protect (“armor”) the underlying Dawson Formation from the rapid erosion that occurs when the less-resistant Dawson is directly exposed to the action of surface water. The landslides within the quadrangle are limited to the Precambrian terrane and are probably late Pleistocene or older; however, modern movement is possible.

STRUCTURAL GEOLOGY

The Rampart Range Fault — The Rampart Range Fault is the largest structural feature in the Palmer Lake quadrangle. This regional-scale, up-to-the-west reverse fault transects the quadrangle north to south, separating the Mesoproterozoic Pikes Peak batholith on the west from younger sedimentary rocks to the east. The fault serves as the southwestern boundary of the Denver Basin from near Sedalia in the north to Colorado Springs in the south. On the basis of cross sections (plate 2) and formation thickness information from other geologic data sources in the region (Thorson and others, 2001; Keller and others, 2005; Morgan and others, 2003; Suttner, 1989; Colorado Oil and Gas Conservation Commission data, Higby #1 wildcat well), we estimate that minimum dip-slip throw along the fault is between 12,800 to 14,500 feet. Displacement on the Rampart Range Fault decreases southward toward Colorado Springs (Trimble and Machette, 1979).

The Rampart Range Fault was observed in outcrop in only one place, at the mouth of Limbaugh Canyon on the north side of Monument Creek. At this location, the fault consists of a zone at least 20 feet wide composed of severely sheared and brecciated rock and clay gouge that locally shows shear foliation. Exposure at this location, however, was not sufficient to determine the overall dip of the fault. Because the material in the fault zone is very soft and friable, it is recessive weathering and it is typically covered by colluvial deposits derived from the erosion of fractured Pikes Peak Granite. These deposits mantle the steep eastern flank of the Rampart Range along the fault. If not covered by Quaternary surficial deposits of mappable thickness, the fault is usually covered by thin sheetwash deposits and/or soil. At some locations we were able to locate the surface trace of the fault because of the close proximity of outcrops of Dawson Formation on the footwall and Pikes Peak Granite on the hanging wall. Also, there is a prominent slope break at or near the fault, and that slope break is often traceable.

We were able to roughly estimate the dip of the fault with three-point solutions at two locations.

Three-point solutions based on locations of the fault trace at and above the mouths of Limbaugh Canyon (W½ sec. 7, T. 11S., R. 67 W.) and the canyon of North Monument Creek (W½ sec. 6, T. 11 S., R. 67 W.) in the northern part of the Palmer Lake quadrangle indicate the Rampart Range Fault in that area is a thrust, dipping 35° to 45° west. However, the Rampart Range Fault may be disrupted across northeast-trending faults that are mapped in the two drainages; thus the three-point solutions may not accurately reflect the true dip of the Rampart Range Fault. Additionally, the strike of the fault may curve and this would make three-point problems inaccurate. Two subsidiary faults which are exposed in these canyons west of the Rampart Range Fault dip similarly to the estimated dip of the Rampart Range Fault based on the three-point solutions.

We estimate that the dip on the Rampart Range Fault steepens to 60° or more along the southern quadrangle boundary, as indicated by a fault exposure on the Cascade quadrangle (Morgan and others, 2003) and the more linear fault trace west of the U.S. Air Force Academy. Thorson (2005b) shows the Rampart Range Fault to be steeper in the Larkspur quadrangle to the north. Dyad Petroleum is planning and permitting two oil and gas test wells in the Mt. Herman area. One of these wells will be spudded in Pikes Peak Granite high in the Rampart Range. If it is drilled and the geologic data is made public, and if the well successfully penetrates the Rampart Range Fault and the sedimentary strata below the fault, the data will give us a much better understanding of the fault geometry.

Pikes Peak Granite in the hanging wall is strongly fractured, locally sheared, and iron-oxide stained for several hundred feet west of the Rampart Range Fault. The iron oxide (mainly hematite) is apparently due to biotite-destructive alteration in the shattered and fractured hanging wall of the fault. Many small, discontinuous faults and slickensided fracture surfaces are present in the highly deformed hanging wall of the fault. Most of these have steep to moderate dips. Only the largest and most persistent of these subsidiary faults are shown on the map.

In the northwestern part of the Air Force Academy, the Rampart Range Fault splits into several splays, exposing thin tectonic slivers or lenses of Upper Cretaceous Niobrara Formation (unit Kn) and the Carlile Shale including the Codell Sandstone Member (unit Kc). The easternmost of these splays places the Niobrara Formation into contact with the Laramie Formation, indicating approximately 6,000 feet of throw. This area is structurally complex. We tentatively interpret that the north-northwest trending lenses of Niobrara Formation and Benton Group form a thin, low- to moderate-angle horst body because the Laramie and Dawson Formations are exposed both east and west of the faulted older formations. Although we scoured the area for outcrops, our mapping does not confirm the presence of Permian and Pennsylvanian rocks west of these fault slivers, as mapped by Varnes and Scott (1967) and Trimble and Machette (1979a). We found only small, limited exposures of the Laramie and Dawson Formations and large areas of Quaternary surficial deposits.

The beds of Niobrara and Codell Sandstone exposed in the horst lens are mostly overturned, dipping from 42° west to vertical. The beds in the Laramie and Dawson Formations west of the horst lens dip moderately to steeply east. We tentatively interpret that the faults that bound the horst dip moderately west, similar to bedding, and the faults intersect the other "main" strand of the Rampart Range Fault at depth. Because we did not find any exposures of the Cretaceous formations north of Hay Creek, we interpret that these fault splays terminate along the concealed continuation of an east-northeast trending tear (?) fault that underlies a steep canyon in the Rampart Range to the west.

Other faults — The granitic rocks of the Pikes Peak batholith in the Rampart Range are cut by several faults of indeterminate throw. Faults are most numerous proximal to the Rampart Range Fault. Most of these faults are steeply dipping to vertical, although at least two north-northeast-trending faults of moderate westerly dip were measured in canyon walls close to the Rampart Range Fault. Because faults in the Rampart Range are very poorly exposed, if at all, and they almost always juxtapose rocks of the same type (Pikes Peak Granite), relative movement along the faults was in most cases not determined. However, an exposure of one such fault exists at a roadcut on a switchback on Balanced Rock Road, ¾-mile south of Upper Reservoir on North Monument Creek. The main splay of this fault is probably covered by colluvium/alluvium in the drainage just west of the roadcut, but several lesser splays are well exposed. Exposed segments dip steeply to the west-northwest. A small aplite dike clearly shows small reverse offset (down to the east). Deep red hematite staining of Pikes Peak Granite is present in places on the exposed fault segments. Hematite-stained grüs or float was used as one of the criteria to determine the presence of other faults that are not exposed in outcrop.

Geomorphic evidence suggests that Mt. Herman, and probably Raspberry Mountain, form a horst block(s), bound on the east by the Rampart Range Fault and on the west by unnamed up-to-the-east faults (cross section A-A', plate 2). The crest of Mt. Herman is significantly higher than other areas underlain by homogeneous Pikes Peak Granite at the same distance from the Rampart Range Fault and the range front. Because the homogenous Pikes Peak Granite otherwise erodes evenly and most hill tops in the Rampart Range are at similar altitudes and form an almost flat surface if connected, the significantly higher relative elevation of Mt. Herman is compelling evidence that it is a structural horst block.

A small, down-dropped structural block is present west of Deadmans Lake along the northwestern boundary of the Air Force Academy grounds. Here, Cambrian Sawatch Sandstone and Ordovician Manitou Limestone overlie Pikes Peak Granite along a nonconformity, dipping east to form the light-colored flatiron feature that is clearly visible from the Air Force Academy and Interstate 25. Nowhere else in the quadrangle are these rocks exposed. A northwest-trending fault truncates the Sawatch Sandstone along the southwestern part of the exposure and is interpreted to be the western bounding fault of the block. Other bounding faults are completely covered by Quaternary surficial deposits or are otherwise not exposed.

Timing of movement on the Rampart Range Fault and other faults — Structural and stratigraphic relationships, along with paleontological constraints in the syntectonic Dawson Formation, show that the bulk of movement and displacement along the Rampart Range Fault took place during the Laramide Orogeny from Late Cretaceous to middle Eocene time (Tweto, 1975 and 1980; Raynolds, 1997). The fault cuts up-section from the Pikes Peak Granite through thick sequences of Lower Paleozoic through Late Cretaceous and Paleocene strata. The overturned bedding in the Niobrara Formation and Laramie Formation indicate the maximum age for the large movement along the Rampart Range Fault is Late Cretaceous. Nearly vertical beds of the Paleocene-Eocene Dawson Formation were mapped along the fault. Progressive unconformities that indicate syntectonic deposition exist in arkosic clastics of the Dawson Formation on the footwall of the Rampart Range Fault (Kluth and Nelson, 1988; Morgan and others, 2003; Raynolds, 2002).

The Rampart Range Fault and/or other faults that cut basement rocks in the quadrangle may have origins in earlier deformational events. These earlier tectonic events may include (1) regional northeast-southwest extension in the foreland or continental interior (intracratonic deformation) during the Grenville orogeny at approximately 1 Ga (Timmons and others, 2001; Marshak and others, 2000); (2) regional east-west extension during breakup of the Rodinia supercontinent at approximately 0.80-0.74 Ga (Timmons and others, 2001); (3) an uplift event in Ordovician time that resulted in the mid-*Rossudus* unconformity (Myrow and others, 2003); and (4) east-northeast/west-southwest convergent tectonics of the Ancestral Rockies event in Pennsylvanian time (Kluth, 1997; Hoy and Ridgway, 2002). Kluth (1997) demonstrated that structures related to the Ancestral Rockies deformation resulted in principally northwest-trending major fault structures, and these are oblique to the dominantly north-south structures of the Laramide orogeny in the Front Range. Regional geological studies elsewhere in the southwestern U.S. show that Laramide deformation reactivated Proterozoic faults (Marshak and others, 2000; Timmons and others, 2001; Heizler, 2002).

Tectonic deformation and tilting of the Rampart Range also occurred in the middle Miocene and again in the latest Miocene, Pliocene, and possibly the Quaternary (Steven and others, 1997). Some movement occurred on the Rampart Range Fault and/or other faults in the Rampart Range as a result of these Neogene events. Coarse, fluvial gravels that were deposited on the late Eocene erosion surface (Epis and Chapin, 1975; Chapin and Kelley, 1997) are preserved as small remnants at two locations high in the Rampart Range in this quadrangle and in more extensive deposits to the southwest near Rampart Reservoir (Scott and Wobus, 1973; Morgan and others, 2003), and near Divide (Epis and Chapin, 1975). These gravels, Miocene in age, have been locally offset by post-Miocene faulting in the Rampart Range (Steven and others, 1997). Although we did not observe any field evidence for Quaternary movement on the Rampart Range Fault in the Palmer Lake quadrangle, Quaternary movement has been documented on the fault further south, in the Cascade quadrangle (Scott, 1970; Dickson, 1986). A small earthquake occurred a few miles north of Palmer Lake in the Perry Park area on December 24, 1994 (see Geologic Hazards section in this report) and suggests that at least some tectonic activity is occurring in the vicinity of the fault to the present day.

Criteria used for mapping faults — Faults that are mapped but not exposed in outcrop were determined using several criteria and lines of evidence. Linear features on aerial photographs and "hillshade" maps created from digital elevation models (DEMs) were often the first line of evidence. Field evidence for faults that are mapped but not exposed in outcrop include deep-red hematite staining of granitic grüs, angular pieces of Pikes Peak Granite float indicating closely spaced fractures, topographic slope breaks and eroded notches or saddles, linear drainages, zones of closely spaced fractures exposed in outcrop, slickensided float (rare), and offset or deflection of the attitudes of widely spaced parallel joint sets. The latter is best observed on aerial photos and can be subtle.

Joints in the Pikes Peak Granite — Widely spaced joints in the Pikes Peak Granite form long, continuous sets that are impressive in aerial photographs and help shape the enormous outcrops that flank the deeper canyons in the Rampart Range. These joints are often not even visible in smaller outcrops in the field because weathering and grüsification of the granite is accelerated along joint planes, leaving only the more resistant granite between the joints exposed as boulder-like corestones at the surface. This process of corestone formation and weathering of the Pikes Peak Granite is well described by Blair (1976).

Joints form two dominant sets in the quadrangle, the most prominent of which strikes west-northwest to east-west and the other north-south to north-northwest (fig. 16). Another joint set, striking northeast, is far less prominent and is found mostly in the southern part of the map area. The joints are all steeply dipping to vertical. We interpret that these joints formed during emplacement of the Pikes Peak Granite as one or more types of primary igneous fractures as identified by Hutchinson (1976). No low-angle joint sets were observed, although some of the narrow aplite dikes dip at low to moderate angles.

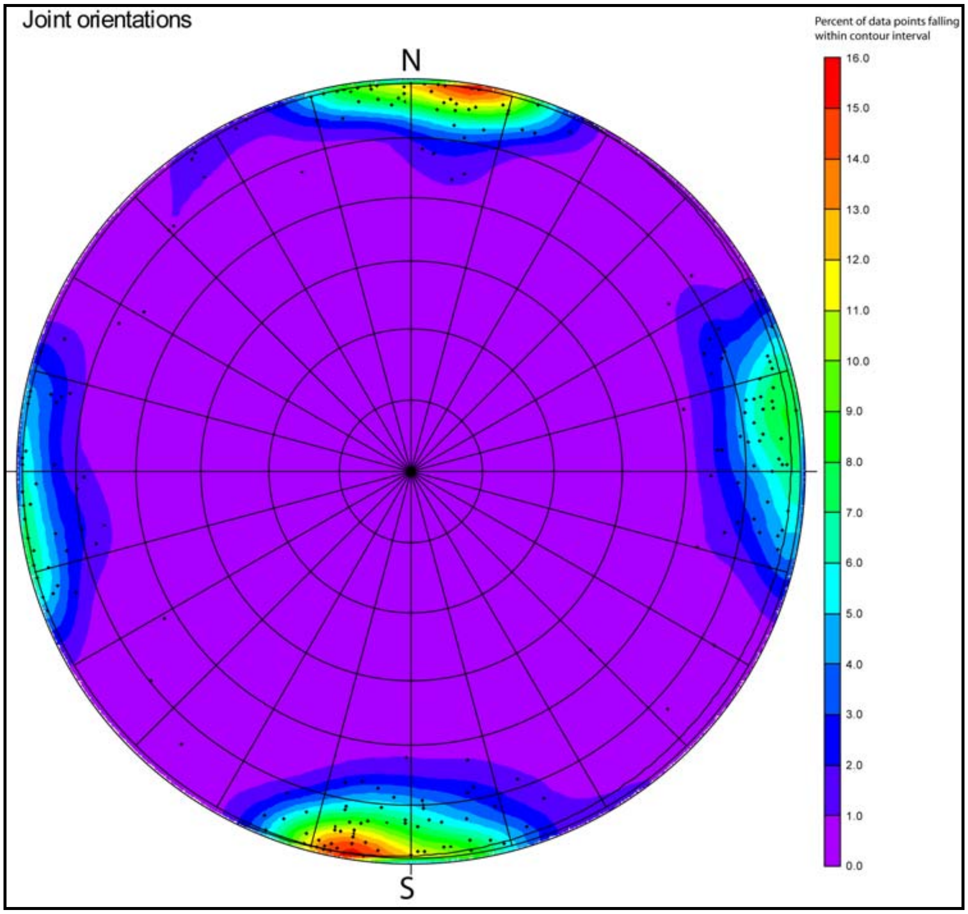

Figure 16. Equal-area, lower hemisphere stereonet diagram showing poles to planes of 229 measured joint surfaces in rocks of the Pikes Peak batholith in the Palmer Lake quadrangle, El Paso County, Colorado. Joints attitudes were recorded according to the right-hand rule. Note the nearly vertical, west-northwest-striking and north-northwest-striking dominant orientations.

Folds — Sedimentary strata are folded to form a long, continuous syncline adjacent to the west-dipping Rampart Range Fault. Because the Dawson Formation is generally poorly exposed along the fault, and bedding in the formation is difficult to measure, in most places there is not good evidence for folding. In some places, the fold may extend only a few feet or tens of feet east of the fault. In others, the eastern limb may extend several hundreds of feet from the fault. Beds of Dawson Formation and Laramie Formation are steeply east-dipping to nearly vertical adjacent to the fault in the southeastern part of the quadrangle. Approximately four hundred feet east of an outcrop of nearly vertical Dawson Formation which is adjacent to the fault, there is another exposure of Dawson that dips only 31° east. The subsurface geometry of the syncline, in older sedimentary formations, is not known. A faulted lens of Niobrara Formation west of a splay of the Rampart Range Fault in that area is overturned, dipping steeply to moderately west.

This fold, or, more precisely, the western limb of the syncline adjacent to the Rampart Range Fault, may be the target of two planned oil and gas test wells that are presently in the permitting process. Dyad Petroleum of Midland, Texas, is proposing to drill two wells near Mt. Herman in the Rampart Range (see the Mineral Resources section of this report). Data from these wells will be valuable to accurately depict the subsurface geometry of the Rampart Range Fault and the adjacent strata.

Primary igneous foliation — Primary igneous foliation (flow structure) was mapped in Windy Point Granite (Ywp) and the syenite unit (Ysy), both of which are mapped only in the southern part of the quadrangle. Hutchinson (1976) describes planar flow structures in the Pikes Peak Granite (unit Ypp) and notes that it is generally difficult to observe and measure. We were able to measure primary igneous foliation at only one location in Pikes Peak Granite, a small zone of schlieren exposed about ¼-mile from the mouth of Limbaugh Canyon on Monument Creek (fig. 17). Schlieren here consists of dark layers having high concentrations of mafic minerals separated by light-colored bands consisting mostly of feldspar and quartz. The schlieren layering strikes N25°W and dips 40° northeast.

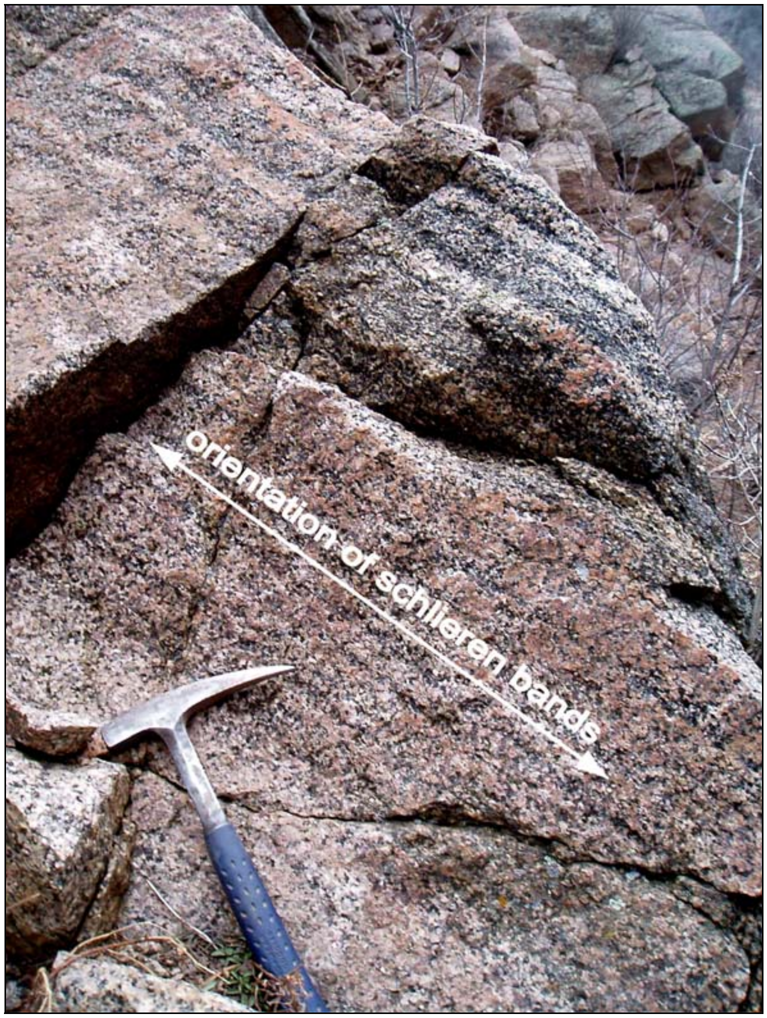

Figure 17. Schlieren bands in Pikes Peak Granite (unit Ypp) exposed in a small area along Monument Creek, about ¼-mile west of the Rampart Range Fault and the mouth of Limbaugh Canyon.

The foliation we measured at a few scattered locations in syenite and Windy Point granite is faint, defined by subtle alignment of feldspar phenocrysts and biotite clusters. The existence of the foliation is partly inferred from the fairly consistent "slabby" weathering pattern of both of these rock units. The slabby weathering pattern might also be interpreted as being caused by fractures or joints. However, the planes that we interpret as being derived from primary igneous foliation are typically slightly undulatory, and the surfaces are not smooth and flat as is normally the case for fractures or joints. Additionally, the foliation generally strikes north-northwest and dips moderately to the west-southwest, whereas joints in the surrounding Pikes Peak Granite are almost always steeply dipping to vertical. Tectonic fractures are usually clustered near faults, whereas the primary foliation is distributed evenly through the rock masses. Moreover, the foliation is largely parallel or subparallel to the contacts of units Ysy and Ywp with enclosing rock types. We interpret that this foliation was developed in response to differential magmatic flow as these slightly later phases of the Pikes Peak batholith were injected into partially cooled and crystallized Pikes Peak Granite.

MINERAL AND ENERGY RESOURCES

Oil and Gas — No hydrocarbon production has yet been achieved within the quadrangle. Two new wildcat exploration wells are proposed in the quadrangle and are in the permitting process as of this writing. Dyad Petroleum Company of Midland, Texas plans to drill these wildcat wells near Mt. Herman in the Rampart Range. The proposed well locations are shown on the geologic map plate that accompanies this report. The nearest productive oil and gas fields to the Palmer Lake quadrangle is from the Hoy Gulch, Wallbanger, and Caledonia fields about 30 miles to the northeast in Elbert County (Wray and others, 2002). Production from these fields is from the Dakota Sandstone.

The Rampart Range Fault defines the southwest margin of the Denver Basin petroleum province in this region. The west-dipping reverse fault places dense, hard, and generally impermeable granitic rocks of the Proterozoic Pikes Peak batholith adjacent to and on top of Paleozoic and Mesozoic sedimentary strata that may contain oil and/or gas resources. The U.S. Geological Survey (1995) recognizes the existence of two hydrocarbon plays associated with the fault. The *subthrust structural play* is a hypothetical conventional play that includes possible production from the sedimentary strata buried under the upthrown mass of Proterozoic granitic rocks. Potential traps are structural and stratigraphic. Hydrocarbons may be trapped in east-dipping reservoir strata under the fault sheet. The fault sheet may be impermeable due to clay gouge, breccia, and the generally impermeable granite in the hanging wall (Jacob, 1983). Soil-gas samples collected in the Rampart Range indicate that hydrocarbons derived from Mesozoic and Paleozoic strata may be migrating upward through Pikes Peak Granite along fractures and faults (Jacob and Fisher, 1985). Samples collected over north-south-trending fractures and faults inferred from aerial photographs contained anomalous concentrations of methane, ethane, propane, and butane.

Potential reservoir rocks in the region include "J" Sandstone of the Dakota Group (Lower Cretaceous), the Codell Sandstone Member of the Carlile Shale (Upper Cretaceous), the Niobrara Formation (Upper Cretaceous), sandstone units in the Pierre Shale (Upper Cretaceous), and the Permian-age Lyons Sandstone (Jacob, 1983). Reservoirs may be associated with fractures. Potential hydrocarbon source rocks regionally include primarily the Graneros Shale (Upper Cretaceous), Greenhorn Limestone (Upper Cretaceous), Carlile Shale (Upper Cretaceous), and the Niobrara Formation (Upper Cretaceous). Carbonaceous shale interbeds are present locally in the Lyons Sandstone (Pennsylvanian) and these may also be a hydrocarbon source (Jacob, 1983). We consider the subthrust structural play to be the most important of the hydrocarbon plays in the Palmer Lake quadrangle.

The U.S. Geological Survey (1995) also recognizes the *basin-margin structural play* along the western and northwestern margin of the Denver Basin Province. The play consists of small anticlines in the Lyons Sandstone proximal to the western edge of the basin. Because the Lyons Sandstone is not exposed in the quadrangle and subsurface data are nonexistent for the formation, it is not known if prospective anticlines are present in that formation.

Shell Oil Company drilled two stratigraphic core holes close to the trace of the Rampart Range Fault between 1953 and 1955. Both were drilled in the NW ¼ Sec. 32, T. 11 S., R. 67 W., near the mouth of the Beaver Creek drainage. The approximate locations of the wells are shown on the geologic map plate accompanying this report. No geologic data or well logs are available from the Colorado Oil and Gas Conservation Commission for either well. The Berry Hill No. 1 was drilled to a depth of 1,910 feet. The Berry Hill No. 2 was drilled to a depth of 562 feet (Colorado Oil and Gas Conservation Commission data). Both wells were abandoned.

Leclair-Westwood, Inc. drilled the Higby #1 wildcat well in 1981 about a mile north of the Palmer Lake quadrangle in the SW¼ SW¼ sec. 27, T. 10 S., R. 67 W. The well (API # 05-035-06011) was drilled to a depth of 9,533 feet and penetrated the “D” Sand, “J” Sand, and Skull Creek intervals of the Dakota Sandstone. No production was achieved and the well was abandoned.

Coal — The eastern part of the Palmer Lake quadrangle is within the Denver coal region and close to the formerly productive Colorado Springs coal field (Carroll and Bauer, 2002). There were never any coal mines in the Palmer Lake quadrangle. However, several underground coal mines once operated in the area 5 to 13 miles south-southeast of the quadrangle boundary in the Pikeview, Colorado Springs, and Elsmere quadrangles. The largest of these mines was the Pikeview, which produced 8,738,174 tons of coal between 1900 and 1957 (Thorson and others, 2001).

In the Pikeview quadrangle, coal was mined from two main seams in the lower part of the Laramie Formation (Kl) of Upper Cretaceous age. The mined seams range in thickness from 3 to 20 feet (averaging between 5 and 10 feet) and are typically lenticular. The coal has heat values that range from 8,000 to 9,310 Btu per pound and ranks as subbituminous B to subbituminous C. Sulfur content ranges from 0.3 to 0.7 percent, volatile matter ranges from 30.2 to 45.1 percent, ash content ranges from 5.4 to 20.8 percent, and moisture varies from 18.2 to 26.9 percent (Thorson and others, 2001).

It is likely that lenticular coal beds are present in the Laramie Formation (Kl) at depth, below the Dawson Formation in the eastern part of the Palmer Lake quadrangle. No coal is present in the small, steeply dipping exposure of Laramie Formation near the Rampart Range Fault on the U.S. Air Force Academy grounds. However, the full stratigraphic thickness of the formation is not exposed in that location.

Sand and gravel aggregate — Sand and gravel aggregate is the only mineral resource actively being exploited in the Palmer Lake quadrangle. The Dellacroce gravel pit in the N½ of sec. 34, T. 11 S., R. 67 W. along the eastern quadrangle boundary is a medium-sized aggregate producer. The site produces an estimated 75,000 tons of gravel per year (Guilinger and Keller, 2004) from Quaternary a deposit of older gravel (unit Qg2). Gravel was mined in the past from two other small pits in the quadrangle (Schwochow, 1981), both of which apparently exploited older gravel deposits (units Qg2 and Qg1).

Pegmatites — Feldspar and quartz were mined in the past from open cuts on two pegmatites in the western part of the quadrangle. Both of the mined pegmatites are enclosed within Pike Peak Granite (unit Ypp). The largest of the pegmatite mines is the Limber Pine, located near the head of the Ice Cave Creek drainage in the far northwestern corner of the map area. Clean, white, crystalline quartz was mined at the Limber Pine pegmatite from a shallow, narrow pit, several hundred feet in length, elongated along strike at roughly N25°W. Most of this mine and the pegmatite it exploited are in the adjoining Mount Deception quadrangle. The Limber Pine mine was permitted as a mining operation by the Colorado Division of Minerals and Geology (DMG) in the 1970s; mining (and the permit) was terminated in 1978. Coarse, pink feldspar is also common in the pegmatite and may have been exploited prior to the 1970s.

Another pegmatite consisting of coarse, pink feldspar, white to grayish quartz, plagioclase feldspar, minor biotite, and zinnwaldite (a lithium-bearing mica) was exploited just west of road FR 313 in the S½ of sec. 7, T. 12 S., R. 67 W. in the south-central part of the mapped area. Zinnwaldite, identified by Foord and Martin (1979) as a common constituent of pegmatites in the Pikes Peak batholith, is tentatively identified here as bladed, tapering, shiny greenish to bronze-colored crystals up to 14 inches long that commonly form in clusters with the long axes of the crystals parallel to each other. The pit is approximately 50 feet long, 20 feet wide, and 15 feet deep, and it trends N15°W, approximately parallel to the strike of the pegmatite. No DMG permit records exist for this mine; it has not been active since before the early 1970s.

Grüs (decomposed granite) — Grüs is formed from the weathering of coarse-grained granite into fragments consisting mainly of individual component mineral grains, principally feldspar and quartz. Grüs is common in areas underlain by Pikes Peak Granite and is thickest on north-facing slopes (Blair, 1976). Elsewhere in the Pikes Peak region grüs has been mined for use as fill material or aggregate. It is a potential resource in the Palmer Lake quadrangle but is not presently being mined.

Metals — No metal production has been recorded in the Palmer Lake quadrangle, and no prospects or occurrences of any metallic minerals, including uranium are known (Wilson, A.B., 2003; Nelson-Moore and others, 1978). The area east of the Rampart Range Fault is mildly prospective for uranium mineralization because sedimentary rocks along the base of the Rampart Range may contain small sandstone-hosted uranium deposits. The most prospective of the formations, regionally, is the Dakota Sandstone, which hosts several small occurrences southwest of Colorado Springs (Nelson-Moore and others, 1978). The Morrison, Fountain, and Dawson Formations also may host uranium mineralization. Little or no potential for metal resources exists in the western two-thirds of the quadrangle, which is underlain by granitic rocks of the Pikes Peak batholith.

GEOLOGIC HAZARDS

The most prevalent geologic hazards in the Palmer Lake quadrangle are rockfall, landslides, and debris flows (mudslides). Significant rockfall deposits occur on the flanks of Ben Lomand Mountain and along the eastern margin of the Rampart Range. Landslides are limited to the Precambrian terrane and do not currently pose a threat to residential dwellings. Debris flows are common in the perennial stream drainages; particularly those drainages emanating from higher elevations where coarse material derived from Precambrian crystalline rocks is available for transport. Although poorly characterized, other significant and potentially damaging hazards in the mapped area include earthquakes, swelling soils, hydrocompactive soils, and erosion.

Landslides — The only mapped landslides in the quadrangle occur within the Precambrian Pikes Peak Granite. These rotational slides appear to have failed along preexisting fractures or fault planes. Slope failure was probably the result of infiltration of fluids which weather and lubricate fractured crystalline bedrock. The landslide deposits consist of cobble to boulder-sized fragments of Pikes Peak Granite set in a grüs matrix. Some of the boulders may reach 25 feet in length. Relative ages of these landslides are difficult to assign; some diverted the drainages on the Rampart surface, which cut and occasionally contain fragments of gravel unit Tg and thus, post-date deposition of unit Tg. Therefore, the landslides may reach a maximum age of late Tertiary; however, recent movement is likely. Due to the remote location of these landslides, they are unlikely to pose a geologic hazard to residential development.

Debris flows (mudslides) — Debris flows, sometimes referred to as mudslides, are dense, heterogeneous mixtures of mud, rock fragments, and plant materials that typically follow preexisting drainages (Varnes, 1978). As the debris flow moves down its valley, its size and power increases, and it incorporates additional materials into the flow. Once the flow reaches an area of lower gradient, the flow drops its load and the suspended sediment is deposited at the mouth of the drainage (Varnes, 1978). Debris flows can form at any point along a drainage including on the sides of valleys. Debris flows are the result of torrential rainfall or very rapid snowmelt runoff, where sediment supply is abundant and easily mobilized (Selby, 1993). Hazard analysis should take into account denuded forest conditions, such as after a wildfire. Such conditions may exist in areas mapped as alluvial fans (Qf), colluvium (Qc), sheetwash (Qsw), colluvium and sheetwash (Qcs), and landslides (Qls). Small debris flows occur in areas mapped as Qa, Qa_1, Qa_2, Qf, Qf_1, and Qf_2. These are of limited extent and are not mapped separately; however, residents should be aware of the possibility of large precipitation events triggering future debris flows that may inundate these areas with dangerous amounts of water and sediment.

Rockfall — Rockfall deposits are grouped into the colluvium (Qc) and colluvium and sheetwash (Qcs) deposits on the Palmer Lake quadrangle. Currently, the most problematic rockfall area surrounds Ben Lomand Mountain where very large blocks of resistant Dawson Formation have calved from the steep cliff face along joint boundaries. Some blocks reach 20 feet in length and several blocks have rolled distances of over 1,000 feet. Residents of the subdivision on the west side of Ben Lomand Mountain should be aware of the potential for future rockfall and rock avalanche events. Developers should use proper rockfall hazard mitigation practices when building new homes in the vicinity of Ben Lomand Mountain.

Extensive colluvium deposits occur along the steep slopes of much of the eastern flank of the Rampart Range and along the steep canyon walls of tributary drainages in Precambrian terrane. Blocks are typically granites of the Pikes Peak batholith with minor fragments of Dawson Formation and Paleozoic sandstones; granite blocks are the largest in size, typically exceeding 25 feet in length. Residential areas at the base of these steep, debris-covered slopes are at risk of future rockfall events, particularly during high precipitation events.

Earthquakes — On December 25, 1994 a magnitude 4.0 earthquake was recorded by the USGS National Earthquake Information Center (NEIC) about 5.6 miles southeast of Castle Rock. The epicentral location was relocated by MicroGeophysics Corporation (1995) to approximately 2.5 miles north of Perry Park at a depth of 14.6 miles. The earthquake was felt at intensity V at Palmer Lake and Larkspur (fig. 18; Kirkham and Rogers, 2000).

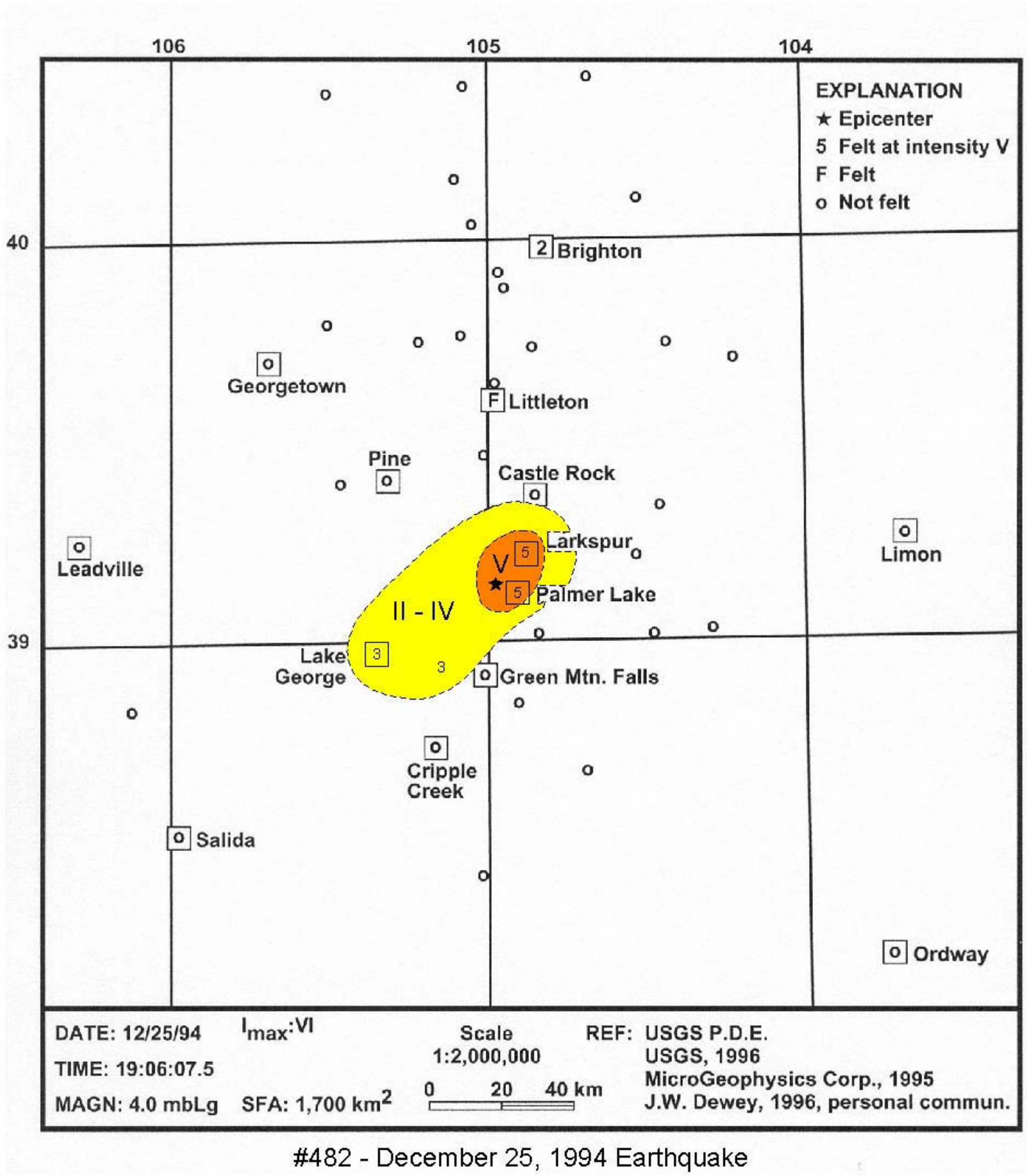

Figure 18. Intensity map of the December 25, 1994 earthquake felt at intensity V near Palmer Lake. From Kirkham and Rogers (2000).

Additional information on faulting and earthquakes in this area is available on the CGS' Colorado Earthquake Map Server (Kirkham and others, 2004) and the Colorado Late Cenozoic

Fault and Fold Database and Internet Map Server (Widmann and others, 2002). Both are available for no charge on-line at *http://geosurvey.state.co.us*.

Swelling soils and heaving bedrock — Expansive or swelling soils and heaving bedrock are one of the most costly geologic hazards along the Front Range Urban Corridor, accounting for tens of millions of dollars in damage (Noe and others, 1997; Noe, 1997). The swelling in surficial materials is caused by the expansion of clay minerals due to wetting. The expansive minerals are commonly derived from layers of bentonitic clay found within the Pierre Shale, other Cretaceous bedrock units, and the Dawson Formation. Heaving bedrock occurs where in-situ shale and claystone layers with high expansive clay content within upturned bedrock are found at shallow depth below the ground surface. When wetted, these clay layers may heave at markedly different rates over small lateral distances. Such differential ground movements can cause significant damage to houses, roads, sidewalks, and other structures (Noe and others, 1997; Noe, 1997).

In the Palmer Lake quadrangle, areas along the mountain front where the Cretaceous formations are upturned, and where soils are derived from these units, are most susceptible to damage caused by expansive clays. Past studies along the Front Range Urban Corridor of potentially swelling soils (Hart, 1974) generally place a low to moderate potential for expansive clays along the eastern margin of the Rampart Range in the Palmer Lake quadrangle. The surficial soils in this area derived from claystones of these formations may also be susceptible. Proper investigation and engineering practices, with a focus on expansive clays and heaving bedrock, should be applied during construction in these areas.

According to the National Resources Conservation Service (NRCS) soil survey data for the Palmer Lake quadrangle, the mapped area is given a low (0-3 Linear Extensibility Percentage (LEP)) swell potential. This category is derived from the linear extensibility of the soil. Linear extensibility refers to the change in length of an unconfined clod as moisture content is decreased from a moist to a dry state. It is an expression of the volume change between the water content of the clod at 1/3 or 1/10 bar tension (33 kilo Pascals (kPa) or 10kPa tension) and oven dryness. The volume change is reported in the table as percent change for the whole soil (LEP). The amount and type of clay minerals in the soil influence volume change (NRCS, 2005).

Hydrocompactive soils — Soils that are susceptible to hydrocompaction (settlement or collapse due to the addition of water) may exist in areas mapped as alluvial fans (Qf), sheetwash (Qsw), colluvium (Qc) and sheetwash (Qcs). Particularly susceptible are the soils derived from the Niobrara, Carlile, and Greenhorn Formations. However, no cases of damage from hydrocompaction have been reported in the mapped area (J. White, personal communication, 2005). According to the National Resources Conservation Service (NRCS) soil survey data for the Palmer Lake quadrangle, the mapped area is given a 0% concentration of gypsum (NRCS, 2005).

Erosive soils — Wind and water runoff are the biggest causes of erosion; however, these are amplified by land development and grazing of vegetated lands where the soil is exposed and easily eroded. Many of the flood plains and outcrops of Dawson Formation are susceptible to moderate soil erosion (NRCS, 2005). Soils derived from the Cretaceous units in west half of sec.

4, T.12 S. R. 67 W. are considered moderately erosive, may form deep gullies, and are prone to soil slippage (NRCS, 2005).

Wind erosion may adversely affect the respiratory functions of humans and livestock by reducing air quality by increasing airborne dust. Furthermore, soil erosion increases the risk of pollution to surface and ground waters due to the use of nutrients and pesticides from agricultural and residential treatment of vegetation.

WATER RESOURCES

SURFACE WATER RESOURCES

The Palmer Lake quadrangle lies almost entirely within the drainage area of Monument Creek. Monument Creek and its tributaries originate in the Rampart Range west of the quadrangle and flow east-northeast across the Mesoproterozoic igneous rocks of the Pikes Peak batholith. At the Rampart Range Fault the streams cross into the Denver Basin and swing to the southeast across unconsolidated Quaternary alluvial deposits overlying early Tertiary sedimentary rock of the Dawson Formation. Monument Creek then continues to the south-southeast to flow into Fountain Creek southeast of the quadrangle in Colorado Springs. Fountain Creek eventually joins the Arkansas River near Pueblo. A very small area on the north flank of Ben Lomand Mountain, just east of Palmer Lake, lies within the drainage area of West Plum Creek, which flows to the north and is tributary to the South Platte River.

The USGS 7.5'-minute topographic map indicates that perennial flow exists in those tributaries to Monument Creek that originate high in the Rampart Range: Ice Cave Creek, North Monument Creek, Monument Creek, North and South Beaver Creeks, and Hay Creek. Those streams that originate closer to the Rampart Range Fault, such as Deadmans Creek are shown as ephemeral. The U.S. Geological Survey Water Resources Data website (http://co.water.usgs.gov/Website/projects/viewer.htm) indicates that stream gage data are available from stations at Palmer Lake, Monument Lake, Monument Creek near the north gate of the Air Force Academy, and Deadmans Creek. The station on the main stem of Monument Creek near the north gate of the Air Force Academy (ID 07103780) is located just downstream of the east edge of the quadrangle boundary. Data collected from this location represent surface water flow conditions from an area covering approximately 82 square miles that includes most of the Palmer Lake quadrangle. Figure 19 is a hydrograph of mean monthly streamflow at this gage station averaged over a ten-year period that shows great seasonal variability. Highest flows have typically been observed in May (averaging 45.4 cubic feet per second [cfs]) and the lowest in January (averaging 4.94 cfs).

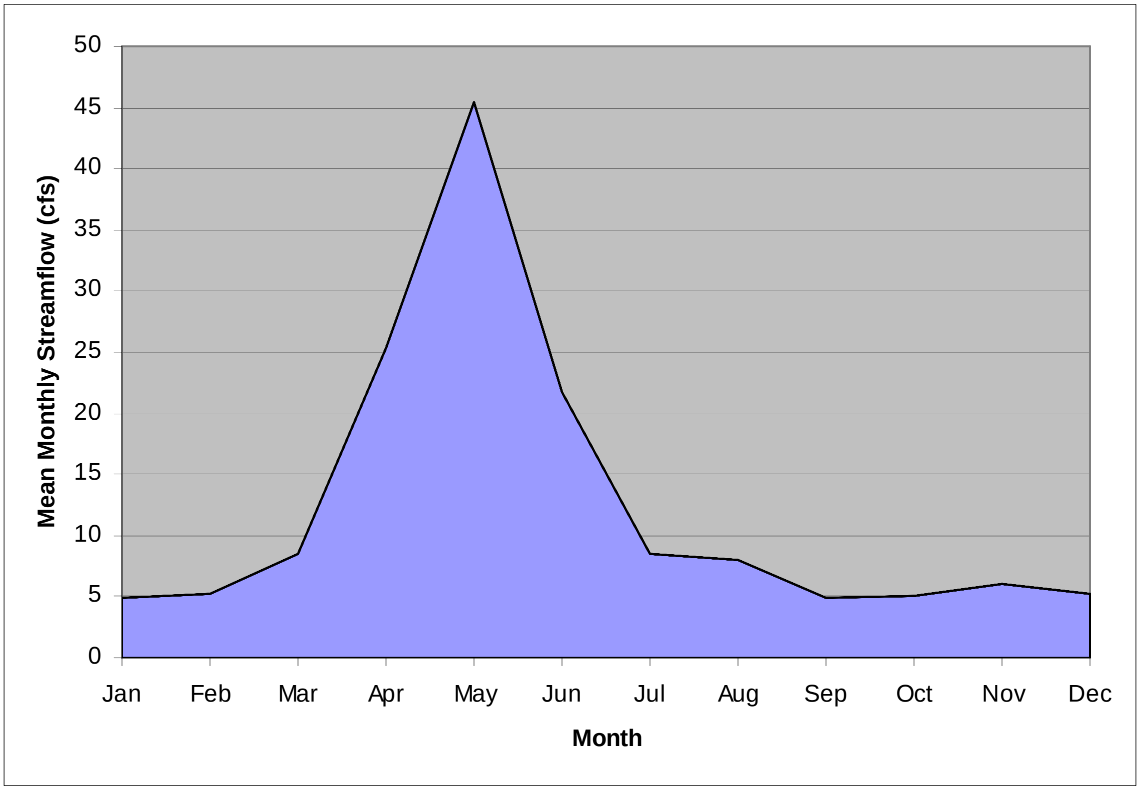

Figure 19. Mean monthly discharge in cubic feet per second (cfs) for Monument Creek near the north gate of the Air Force Academy (ID 07103780). Data is from the U.S. Geological Survey Water Resources Data website (U.S. Geological Survey, 2005) and covers the period of 1985 through 2004.

Monument Creek is within Water Division 2, District 10 of the Colorado Division of Water Resources (DWR), the agency responsible for administering water usage in the state. West Plum Creek is within Water Division 1, District 8. The use of surface water in Colorado is governed by the "Prior Appropriation System" (see http://water.state.co.us/wateradmin/prior.asp, or CFWE, 2003). Surface water in the quadrangle has been diverted via headgates on the streams for a variety of purposes including irrigation, municipal, and domestic. A tabulation of water rights for this division is available at http://water.state.co.us/pubs/tabulation/div2_tabulation.pdf . Recent urbanization of the area has driven usage away from historical irrigation purposes to municipal. Water is stored in a number of reservoirs, both large and small. The largest are found on North Monument Creek (Upper and Lower Palmer Reservoirs), Monument Creek (Monument Lake), and South Beaver Creek (Carrol Lakes). Other small capacity ponds can be found on several of the tributaries as well.

GROUND WATER RESOURCES

Ground water provides a primary water source for municipal and domestic purposes throughout the Palmer Lake quadrangle. Depending on location, ground water can be found in one, or a combination of, three hydrogeologic units: (1) Quaternary alluvial aquifers along the streams that run through the quadrangle, (2) consolidated bedrock aquifers found in the late Cretaceous and Tertiary sedimentary deposits of the Denver Basin, and (3) the fractured crystalline rock aquifer within the Mesoproterozoic Pikes Peak batholith. Paleozoic and Mesozoic sedimentary rocks which lie stratigraphically below the Upper Cretaceous and Tertiary rocks mentioned above are potential aquifers at depth in the Denver Basin, east of the Rampart Range Fault. However, these formations are found only at great depth and could only be tapped at considerable expense.

The following sections briefly summarize each of these hydrogeologic units and provide general hydrogeologic characteristics gathered from available literature. The scope of this discussion is limited to providing a broad description of the ground-water resources that might be available within the quadrangle. Further details, such as specifics about water quality conditions and current water level data can be obtained from cited literature.

Quaternary alluvium — The quaternary alluvial deposits associated with the main stem of Monument Creek form a local aquifer in the northeastern corner of the quadrangle. After crossing the Rampart Range Fault, Monument Creek flows in a southeasterly direction from just south of the Town of Palmer Lake to the Town of Monument. In this reach the stream follows a well-defined valley underlain with alluvial sand and gravel derived from igneous rocks exposed in the Rampart Range as well as locally exposed sedimentary rocks of the Dawson Formation. The aerial extent of the alluvium, depicted on the geologic map as Qa_1, Qa_2, and Qa_3, is limited to a relatively narrow band approximately 500 to 1,500 feet wide along the stream. Elsewhere in the quadrangle, alluvium is present beneath the surface streams but the deposits are very limited in extent and depth. With the exception of a well near South Beaver Creek and another near Hay Creek, alluvial deposits away from the main stem of Monument Creek do not appear to have been tapped by wells for ground water (DWR online mapping site: http://165.127.23.116/website/lttools/ accessed December 2005). Ground water may be present anywhere in the alluvium depending on location relative to surface water and surface-water flow conditions.

The well permit files maintained by DWR provide limited thickness data for the alluvium. Accurate geologic logs for wells in the alluvium in this area are rare. However, reported well depths can be used to estimate the thickness of alluvium. The characteristics of the unconsolidated alluvium are also similar to the underlying Dawson Formation sandstone deposits, further obscuring clear definition of a basal contact. On the basis of well records and the topographic expression of the alluvial valleys, the thickness of the alluvium in Monument Creek may be as great as 100 feet just upstream from Monument Lake.

The alluvium is in direct hydraulic connection with the streams and forms an unconfined aquifer where saturated with ground water. Obviously, the aerial extent of the alluvial aquifer roughly coincides with the aerial extent of the alluvium; however, the alluvium is not always saturated with ground water and the presence of alluvium at the surface does not necessarily imply the presence of an aquifer at depth. Records obtained from DWR indicate water levels in wells completed in the alluvial aquifer generally lie between the surface and approximately 50 feet below the surface. The aerial extent of the alluvial aquifer, therefore, would be expected to be somewhat smaller than that of the alluvium.

According to DWR permit files (reviewed through January 2005), ten wells tap the alluvial aquifer along Monument Creek. The coarse-grained nature of the unconsolidated alluvium allows relatively high well yields despite limited depth and aerial extents with yields reported up to 100 gallons per minute (gpm). Published water quality data from the alluvial aquifer within the quadrangle are limited; however, in general, the water quality is good and suitable for human consumption as well as all other municipal, agricultural, and industrial uses. At some locations within the region, particularly north of Palmer Lake in the Plum Creek drainage basin, ground water in the alluvial deposits contains concentrations of iron, manganese, nitrate, and selenium that exceed applicable drinking water standards (Hillier and Hutchinson, 1980).

The Denver Basin bedrock aquifer system — The Denver Basin bedrock aquifer system is held within the sedimentary sequence filling a large structural basin that extends across much of northeastern Colorado. As defined by the outcrop of the Fox Hills Sandstone, the aquifer system covers an area of approximately 6,700 square miles spanning much of the region between Denver and Colorado Springs. It supplies ground water for domestic, commercial, municipal, and agricultural purposes throughout much of this urbanized area and is a layered multi-aquifer system comprised of Eocene through Upper Cretaceous sedimentary deposits of the Dawson Formation, Laramie Formation, and Fox Hills Sandstone. The aquifers underlie the eastern one-third of the Palmer Lake quadrangle and form the primary water supply where surface water resources are either unavailable or seasonally unreliable.

Details of the stratigraphy of the sedimentary sequence that forms the Denver Basin aquifer system are provided elsewhere in this document; however, the sequence consists of interbedded sandstone, conglomerate, siltstones, and shale with coal present locally throughout the sequence. Ground water is produced from the more porous and permeable sandstone layers of the sequence. Specific hydrogeologic characteristics of the aquifers are well summarized in the Ground-Water Atlas of Colorado (Topper and others, 2003).

For purposes of allocating this regionally vital ground water resource, the Denver Basin bedrock aquifer system has been subdivided by statute into the Dawson, Denver, Arapahoe, and Laramie-Fox Hills aquifers. Separation of the aquifers is based on correlation of laterally extensive shale-dominant confining layers identified by the USGS and the DWR on borehole geophysical logs, primarily gamma-ray and resistivity logs (Romero, 1976; Graham and VanSlyke, 2004). Water rights allocations and well permits are granted based on these designations. The DWR has prepared a series of structural contour maps showing the elevation of the top and base of each of the Denver Basin aquifers based on the correlations of the confining layers separating the aquifers. These maps are part of the Denver Basin rules (Colorado Division of Water Resources, 1986) and are used for estimating well depths prior to drilling.

The Dawson, Denver, and Arapahoe aquifers are within the Dawson Formation as mapped in this area. Currently, there are no direct and consistent correlations between the statutorily defined aquifers and the different facies units described in this booklet. Differentiation of the aquifers has traditionally been made using subsurface characteristics identified on geophysical logs, while differentiation of the different facies units is based on surface exposure characteristics. Current investigations by the CGS seek to clarify the correlations between surface and subsurface differentiations. The Laramie-Fox Hills aquifer is comprised of fluvial sandstones found within the Upper Cretaceous Laramie Formation and Fox

Hills Sandstone.

The Denver Basin bedrock aquifers are abruptly folded up against the Rampart Range Fault. Within this quadrangle the Dawson Formation is in direct contact with the Rampart Range Fault over much its length. The deeper Laramie Formation and Fox Hills Sandstone have been truncated by the fault. Dips in the Dawson Formation measured at outcrops decrease rapidly away from the fault into the Denver Basin and it is likely that portions, or all, of the Dawson, Denver, and Arapahoe aquifers are exposed at the surface in a narrow belt paralleling the fault. Because of the structural shape of the basin and the increase in surface elevation to the north, the depths of the aquifers increase to the north-northeast where the estimated depths to the base of each aquifer from ground surface as are follows: Dawson aquifer up to 1,100 feet, Denver aquifer up to 1,950, Arapahoe aquifer up to 2,500, and Laramie-Fox Hills aquifer up to 2,900. The Dawson aquifer is not present south of about Hay Creek due to erosion.

Water level data for the Denver Basin aquifers can be obtained from the DWR well permit files. Well completion reports and pump installation reports that are required to be submitted often have listed water levels recorded when the wells were completed. However, water level information does not necessarily represent static conditions in the well and the data are one-time measurements. Water levels in the Denver Basin bedrock aquifers are site-specific and can be expected to vary considerably depending on location and elevation. Water levels in this area are also decreasing as the aquifers are being exploited. The DWR measures water levels in a number of select wells throughout the Denver Basin on an annual basis in order to track regional water level changes (VanSlyke, 2004). Data from wells in the Woodmore area, just east of the quadrangle, indicate that water levels in the Dawson and Denver aquifers are relatively stable, while the water levels in the Arapahoe aquifer are falling approximately 20 feet per year. Little published data are available for Laramie-Fox Hills wells in the vicinity of this quadrangle.

With the exception of the Dawson aquifer, there is little connection between the Denver Basin bedrock aquifers and surface water. Because of this, much of the ground water in the Denver Basin bedrock aquifers is considered by the State of Colorado to be “non-tributary”, and therefore it is not directly part of the overlying system of surface and alluvial water rights. Description of the definition of the “non-tributary” classification and details of management of the water rights in the Denver Basin bedrock aquifers is spelled out in the Denver Basin rules (Colorado Division of Water Resources, 1986). More importantly, because of the poor connection with surface water, recharge is very limited and the ground-water resource should be considered non-renewable.

Water quality data for the Denver Basin bedrock aquifers has been summarized in a set of maps published by the USGS (Robson and Romero, 1981a, 1981b; Robson and others, 1981a, 1981b). Hillier and Hutchinson (1980) also presented limited data on near-surface water quality of the Dawson aquifer. Otherwise, little water quality information from locations within the Palmer Lake quadrangle is published. In general, the water quality of the Denver Basin aquifers is adequate for domestic uses. However, there can be concerns with elevated total dissolved solids (TDS) and sulfate in the Denver and Laramie-Fox Hills aquifers elsewhere in the Denver Basin. Elevated concentrations of dissolved iron and manganese have also been reported in water from each of the aquifers (for example, DWR permit file for Arapahoe aquifer well 23055-F).

Fractured crystalline rock aquifer — Igneous rocks underlie the western two-thirds of the Palmer Lake quadrangle and form a "fractured crystalline rock aquifer". Where alluvium is not present, the fractured crystalline rock aquifer is the only source of ground water. Since primary porosity is essentially non-existent, water is produced from fractures and fault zones. Locally, it is also possible to complete a well in weathered granite, or grüs, if the depth of weathering is great and the site close to perennial surface water. Finding productive fractures or fracture zones is very unpredictable and yields can be quite low. Recharge is typically from infiltration of precipitation and snowmelt and there is a delicate balance between aquifer recharge and consumption (Topper and others, 2003).

Despite underlying such a large portion of the quadrangle, the fractured crystalline rock aquifer is not widely exploited. Most of the land underlain by Pikes Peak Granite is within the Pike National Forest and there is little demand for direct utilization of ground water. On the other hand, the area is watershed for Monument Creek and its tributaries. In this setting, the fractured crystalline rock aquifer serves as a vital water reservoir, discharging base flow to the streams during periods of low precipitation. The DWR permit files indicate that, as of January 2005, 14 wells are completed in the fractured crystalline aquifer and most are in the upper Beaver Creek drainage at Carrol Lakes. These wells range in depth from 15 to 840 feet and have reported yields ranging between 0.2 and 40 gpm. Water levels vary considerably from near the surface to 320 feet below the surface, with the shallow water levels in valleys near perennial streams. Published water quality data are not available for this area.

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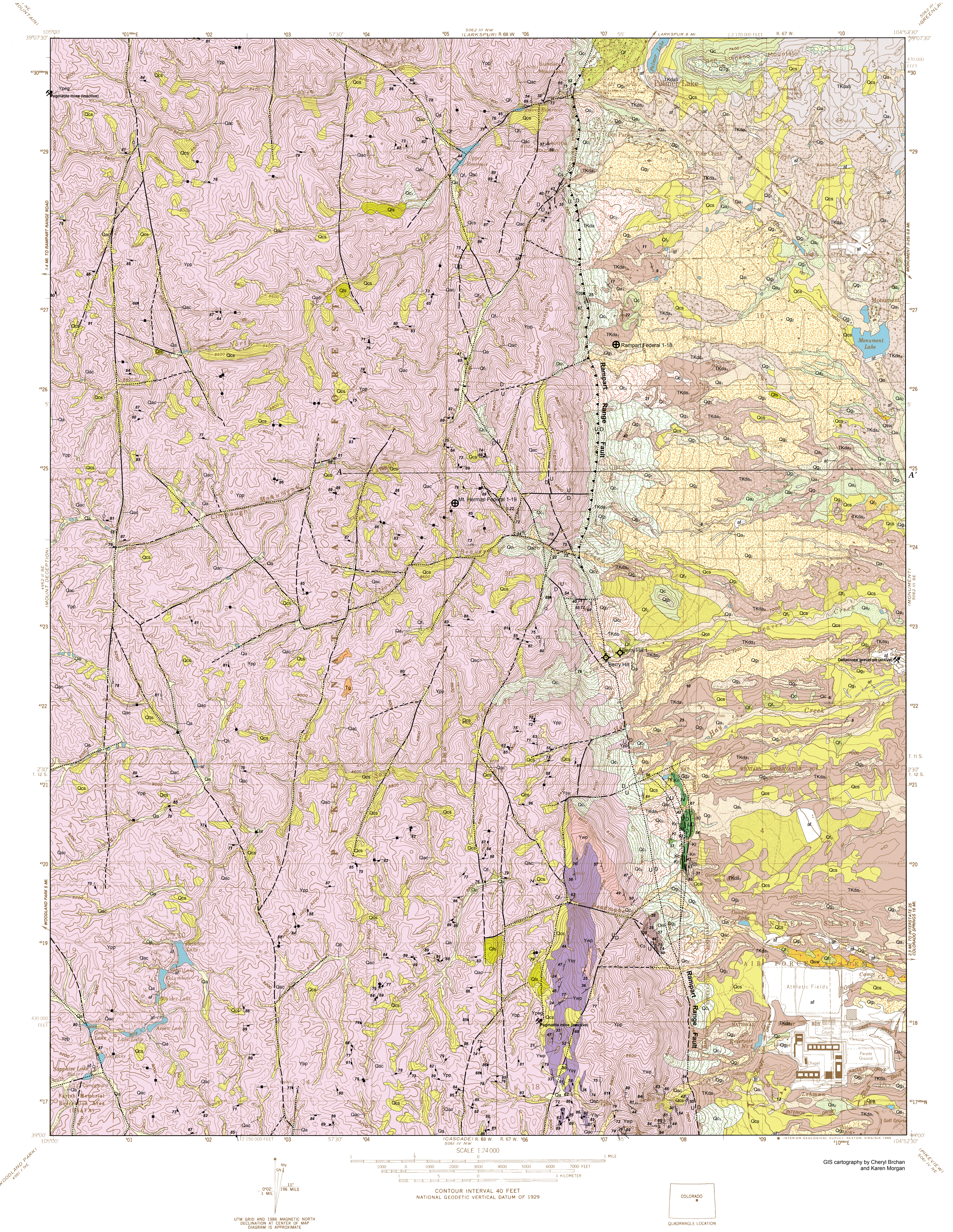
COLORADO GEOLOGICAL SURVEY
DEPARTMENT OF NATURAL RESOURCES
DENVER, COLORADO

OPEN-FILE 06-6
GEOLOGIC MAP OF THE PALMER LAKE QUADRANGLE
EL PASO COUNTY, COLORADO
Plate 1 of 2
Booklet accompanies map



LIST OF MAP UNITS

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

SURFICIAL DEPOSITS

HUMAN-MADE DEPOSITS

- af — Artificial fill (latest Holocene)

ALLUVIAL DEPOSITS

- Qa — Stream-channel, flood-plain, and terrace alluvium, undivided (Holocene and late Pleistocene)
- Qa_1 — Alluvium one (late to early Holocene)
- Qa_2 — Alluvium two (late Pleistocene)
- Qac — Stream alluvium and colluvium, undivided (Holocene to late Pleistocene)
- Qsw — Sheetwash alluvium (Holocene and late Pleistocene)
- Qf_1 — Alluvial fan deposit one (late Holocene)
- Qf_2 — Alluvial fan deposit two (early Holocene to late Pleistocene)
- Qf_3 — Alluvial fan deposit three (late Pleistocene)
- Qf — Alluvial fan deposit (Holocene to late Pleistocene)
- Qg_1 — Gravel deposit one (middle Pleistocene)
- Qg_2 — Gravel deposit two (early middle Pleistocene)
- Qg_3 — Gravel deposit three (early Pleistocene)
- QTg_4 — Gravel deposit four (early Pleistocene or late Eocene?)
- Tg — Gravel (late Tertiary)

MASS-WASTING DEPOSITS

- Qcs — Colluvium and sheetwash alluvium deposits, undivided (Holocene and late Pleistocene)
- Qc_1 — Colluvium deposit one (Holocene to late Pleistocene)
- Qc_2 — Colluvium deposit two (middle to late Pleistocene)
- Qc — Colluvium deposits, undivided (Holocene to late Pleistocene)
- Qls — Landslide deposits (Holocene to late Tertiary)

BEDROCK

TERTIARY AND UPPER CRETACEOUS CONTINENTAL SEDEMENTARY ROCKS

- TKda — Dawson Formation, undivided (Upper Cretaceous to middle? Eocene)—Shown only on cross sections
- $TKda_5$ — Dawson Formation, facies unit five (early to middle? Eocene)
- $TKda_4$ — Dawson Formation, facies unit four (Paleocene)
- $TKda_3$ — Dawson Formation, facies unit three (Paleocene)
- $TKda_1$ — Dawson Formation, facies unit one (Upper Cretaceous to Paleocene)

MESOZOIC SEDIMENTARY ROCKS

- Kl — Laramie Formation (Upper Cretaceous)
- Kfh — Fox Hills Sandstone (Upper Cretaceous)—Shown only on cross sections
- Kp — Pierre Shale (Upper Cretaceous)—Shown only on cross sections
- Kn — Niobrara Formation (Upper Cretaceous)
- Kc — Carlile Shale, including Codell Sandstone Member (Upper Cretaceous)
- Kcgg — Graneros Shale, Greenhorn Limestone, and Carlile Shale, undivided (Upper Cretaceous)—Shown only on cross sections
- Kdp — Dakota Sandstone and Purgatoire Formation (Lower Cretaceous)—Shown only on cross sections
- Jmr — Morrison Formation and Ralston Creek Formation (Upper Jurassic)—Shown only on cross sections

PALEOZOIC AND LATEST MESOZOIC SEDIMENTARY ROCKS

- TsPr — Lower Triassic?, Permian, and Pennsylvanian rocks, undivided)—Shown only on cross sections
- Om — Manitou Limestone (Lower Ordovician)
- Cs — Sawatch Sandstone (Upper Cambrian)

MESOPROTEROZOIC IGNEOUS ROCKS OF THE PIKES PEAK BATHOLITH

- Ypeg — Pegmatite (Mesoproterozoic)
- Ywp — Windy Point Granite (Mesoproterozoic)
- Ysy — Syenite (Mesoproterozoic)
- Ypp — Pikes Peak Granite (Mesoproterozoic)

SYMBOLS

- Contact—Approximately located
- D 65 U — High-angle fault—Dashed where approximately located; dotted where concealed; queried where inferred. U on upthrown side; D on downthrown side. Tic indicates direction of dip; tic number indicates field measurement of dip magnitude.
- Thrust fault—Dotted where concealed. Barbed teath are on overthrust block side of fault
- Strike and dip of bedding or contacts
  - 70 — Inclined—Showing direction and angle of dip
  - 42 — Overturned—Showing direction and angle of dip
- Strike and dip of fractures
  - 75 — Inclined—Showing direction and angle of dip
  - Vertical
- Strike and dip of joints
  - 67 — Inclined—Showing direction and angle of dip
  - Vertical
- 45 — Primary igneous foliation—Showing direction and angle of dip
- 5 55 — Shear fracture with slickenslide lineation—Showing direction and angle of dip, and trend and plunge of lineation
- Mine or gravel pit
- Proposed oil and gas test well
- Existing oil and gas exploratory well (abandoned)
- Water
- A A′ — Line of cross section

GEOLOGIC MAP OF THE PALMER LAKE QUADRANGLE, EL PASO COUNTY, COLORADO

By John W. Keller, Matthew L. Morgan, Jon P. Thorson, Neil R. Lindsay, and Peter E. Barkmann
2007

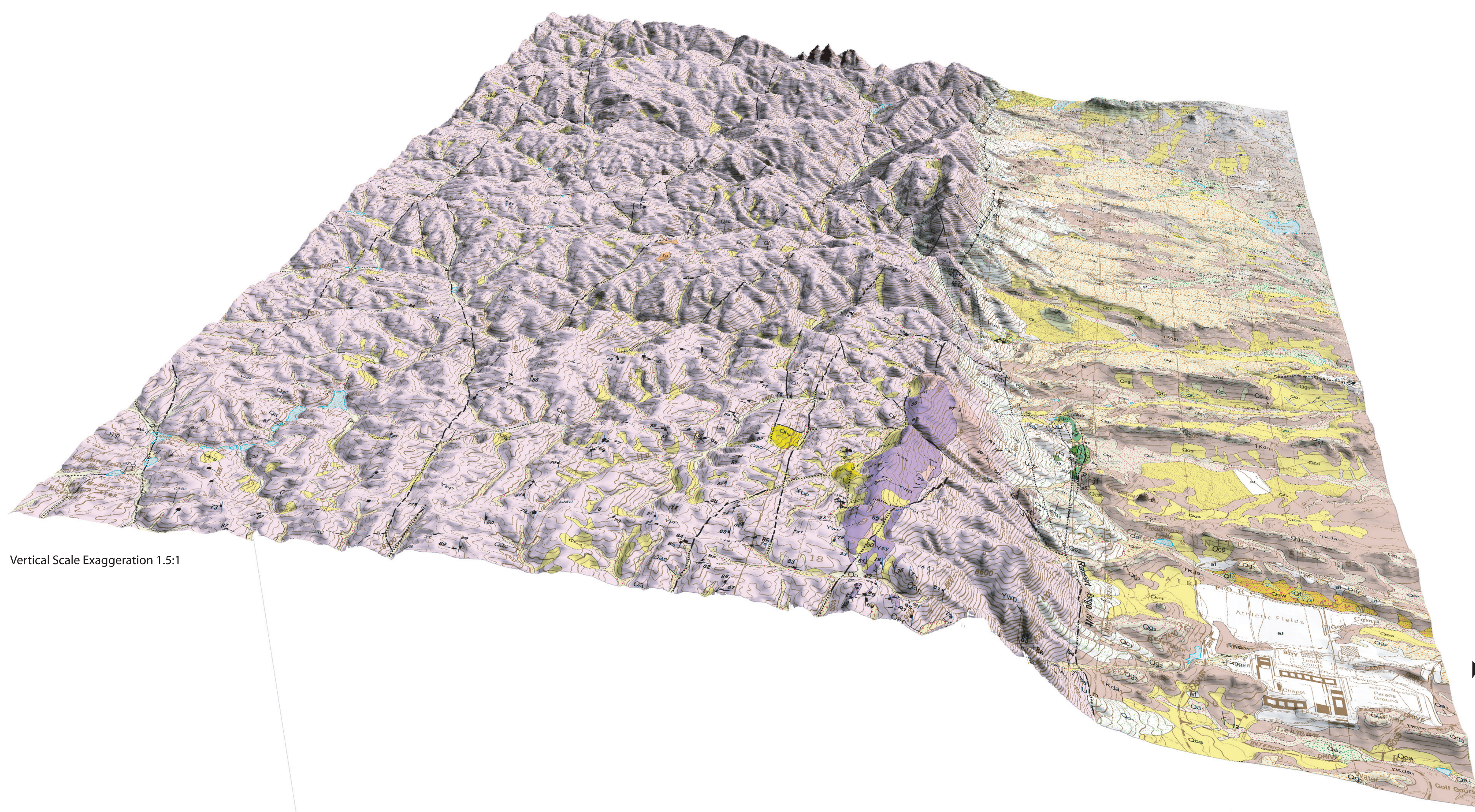
Bill Ritter Jr., Governor
State of Colorado

Harris D. Sherman, Executive Director
Department of Natural Resources

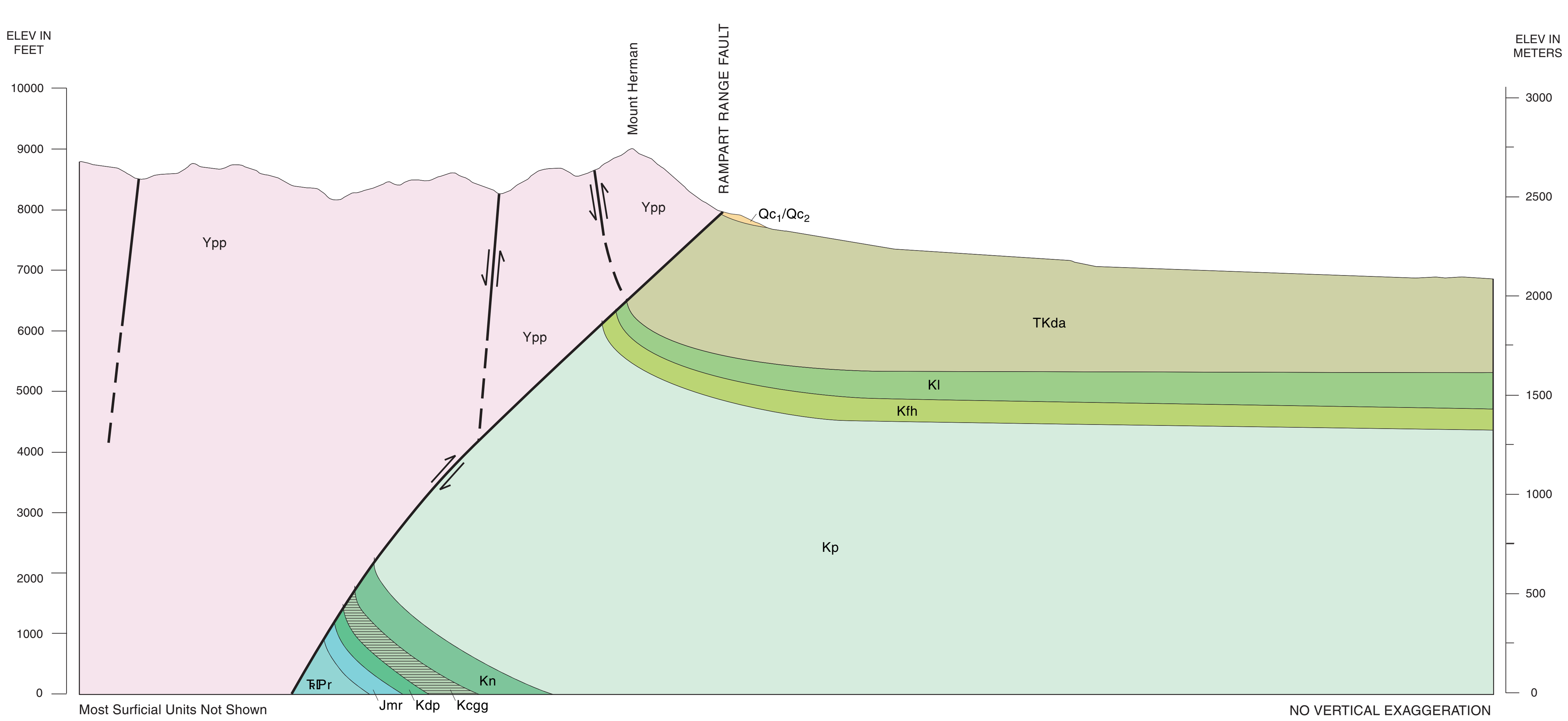
Vincent Matthews
State Geologist and Division Director
Colorado Geological Survey

COLORADO GEOLOGICAL SURVEY
DEPARTMENT OF NATURAL RESOURCES
DENVER, COLORADO

3-D OBLIQUE VIEW

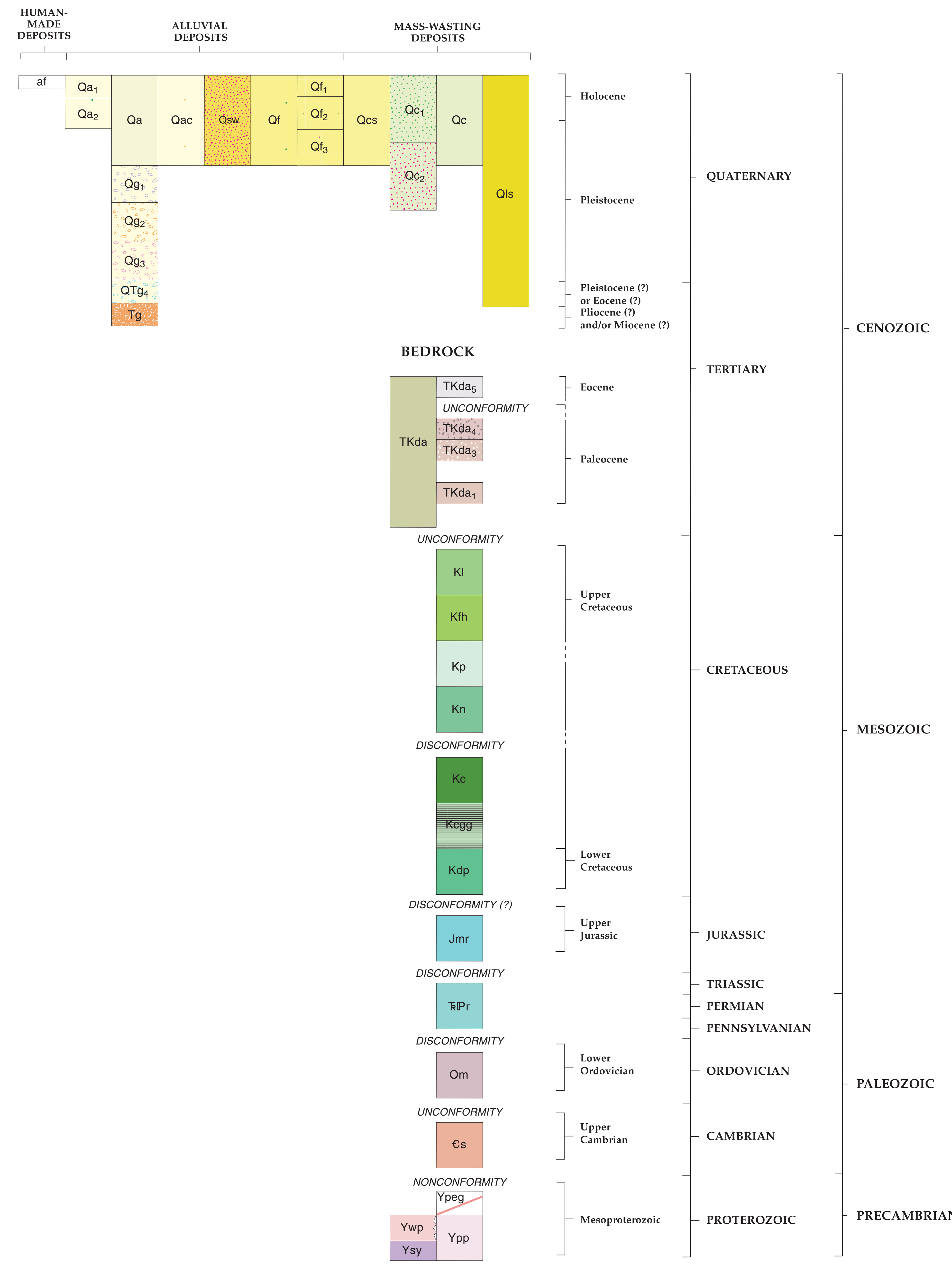


CROSS SECTION A- A′



CORRELATION MAP UNITS

SURFICIAL DEPOSITS



MAP COMPONENTS TO ACCOMPANY GEOLOGIC MAP OF THE PALMER LAKE QUADRANGLE, EL PASO COUNTY, COLORADO

By John W. Keller, Matthew L. Morgan, Jon P. Thorson,
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