OPEN-FILE REPORT 08-17

Authors' Notes

Geologic Map of the Larkspur Quadrangle, Douglas and El Paso Counties, Colorado

By

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Colorado Geological Survey
Department of Natural Resources
Denver, Colorado
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Geologic Map of the Larkspur Quadrangle, Douglas and El Paso Counties, Colorado

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

By
Jon Thorson, Jay Temple, Alan Busacca, and William Berg

Lower Permian and Pennsylvanian Fountain Formation outcrops on the Sandstone Ranch (foreground); Pikes Peak Granite core of Rampart Range (background). [UTM83 504947, 4342062]

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. 07HQAG0083

Colorado Geological Survey
Department of Natural Resources
Denver, Colorado
2008

FOREWORD

The purpose of Colorado Geological Survey Open File Report 08-17, *Geologic Map of the Larkspur Quadrangle, Douglas and El Paso Counties, Colorado* is to describe the geologic setting and mineral resource potential of this 7.5-minute quadrangle located in central Colorado. Consulting geologist Jon P. Thorson completed the field work on the eastern half of the quadrangle during the summer of 2004. Consulting geologists Jay Temple and Alan Busacca completed the field work on the western half of the quadrangle during the summer of 2007. Hydrogeologist William Berg has been a consultant for a major landowner in the western half of the quadrangle since 2005 and added considerable detail to the groundwater resource section of the report.

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, award numbers 04HQPA0003 and 07HQAG0083, and the Colorado Geological Survey using the Colorado Department of Natural Resources Severance Tax Operational Funds. The CGS matching funds come from the Severance Tax paid on the production of natural gas, oil, coal, and metals.

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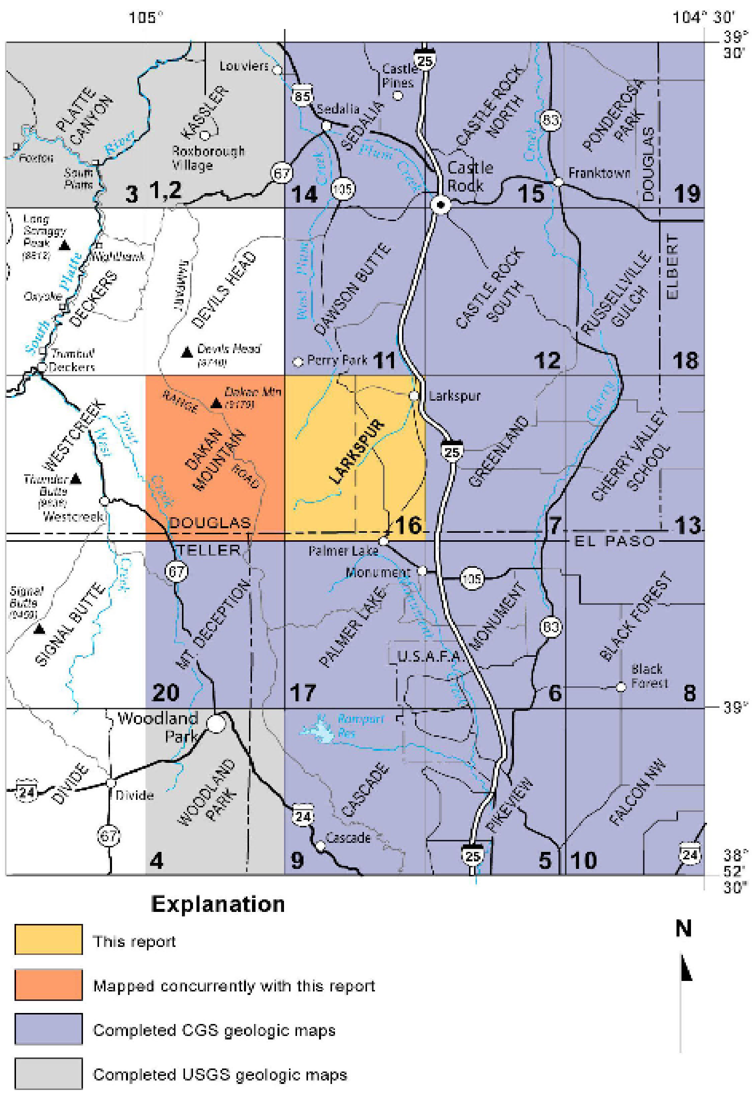
INTRODUCTION

The Larkspur 7.5-minute quadrangle is located southwest of Castle Rock, Colorado, in the southern part of the Colorado Piedmont section of the Great Plains. The quadrangle is located near the head of the Plum Creek drainage, which is tributary to the South Platte River. Geologic mapping of the Larkspur quadrangle was undertaken by the Colorado Geological Survey (CGS) as part of the STATEMAP component of the National Cooperative Geologic Mapping Program. 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 evaluation. Figure 1 shows the location of the Larkspur quadrangle and the status of geologic mapping of 7.5-minute quadrangles in the area.



Completed 1:24,000-scale geologic maps:

Index Map No.	Publication No.	Date
1	USGS PP-421-A Scott	1963
2	USGS PP-421-B Scott	1963
3	USGS B-1181C Peterson	1964
4	USGS MF-842 Wobus and Scott	1977
5	CGS OF 01-3 Thorson and others	2001
6	CGS OF 02-4 Thorson and Madole	2002
7	CGS OF 03-9 Thorson	2003
8	CGS OF 03-6 Thorson	2003
9	CGS OF 03-18 Morgan and others	2003
10	CGS OF 03-8 Madole	2003
11	CGS OF 04-7 Morgan and others	2004
12	CGS OF 04-5 Thorson	2004
13	CGS OF 04-6 Thorson	2004
14	CGS OF 05-6 Morgan and others	2005
15	CGS OF 05-2 Thorson	2005
16	CGS OF 05-7 Thorson (previous, east half only)	2005
17	CGS OF 06-6 Keller and others	2006
18	CGS OF 06-8 Thorson	2006
19	CGS OF 07-4 Thorson	2007
20	CGS OF 07-7 Temple and others	2007

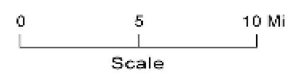


Figure 1. Index map showing the location of the Larkspur quadrangle and adjacent 1:24,000 scale mapping by the U.S. Geological Survey and Colorado Geological Survey.

In this study, the eastern half of the quadrangle was mapped in 2004 and the western half in 2007 because of property access issues resulting from large land sales within the quadrangle during this time period. This map is based on prior published and unpublished geologic maps and reports, interpretation of aerial photography, and field mapping in 2004 and 2007. The aerial photographs used are approximately 1:15,840 scale color photographs taken in 1975 and 2005. The topographic base map for the Larkspur quadrangle was published in 1994. Consequently, some of the recently constructed roads, buildings, and other human-made modifications of the landscape may not be shown on the base map.

Previous geological mapping in the Larkspur area includes the work of Emmons and others (1896) and Richardson (1915). Trimble and Machette (1979a) published a 1:100,000 scale regional geologic map of the Front Range urban corridor which includes the Larkspur quadrangle. Bryant and others (1981) compiled a 1:250,000 scale map covering the Larkspur quadrangle. Maberry and Lindvall (1972, 1977) mapped the Parker and Highlands Ranch quadrangles, located northeast of the Larkspur quadrangle, at a scale of 1:24,000. Scott, (1962, 1963a, 1963b) mapped the Littleton and Kassler quadrangles at a similar scale. Recent mapping adjacent to the Larkspur quadrangle by the Colorado Geological Survey is shown in figure 1.

The names and symbols used for geological units in the Larkspur quadrangle conform as much as possible to those employed previously on geologic maps of nearby areas prepared by the Colorado Geological Survey (fig. 1). The names and symbols for many of the surficial and bedrock units used by Maberry and Lindvall (1972, 1977) do not conform to the geologic formations currently used by CGS. The approximate correlations with earlier geological units are described in the "Description of Map Units" section of this text. The scale of the base map and aerial photographs governed the minimum size of the deposits shown on the map. With few exceptions, deposits that have minimum dimensions of less than 150 ft were not mapped. Also, deposits that are less than 5 ft thick were not mapped unless they are coincident with land forms that can be delineated on aerial photography. Some of the surficial deposits of the Larkspur quadrangle are not well exposed. Consequently, the thickness of most units is estimated and descriptions of physical characteristics such as texture, stratification, and composition are based on observations at a limited number of localities.

ACKNOWLEDGEMENTS

This mapping project was funded jointly by the Colorado Geological Survey and the U.S. Geological Survey through the National Geological Mapping Program. Many people from the Colorado Geological Survey have earned our thanks: Matt Morgan and Vincent Matthews reviewed the map and text. Matt Morgan and Jason Wilson were valuable help in converting notes and field mapping on aerial photos into the geological map. Nick

Watterson assembled the final cartography and booklet. Nick Watterson and Larry Scott provided key assistance in the digitizing of maps, cross sections, and the production of figures for this report. Jane Ciener was technical editor. Special thanks go to the landowners and developers who granted permission to enter their property.

GEOLOGICAL SETTING

The Larkspur quadrangle is located near the western edge of the Denver Basin, an asymmetrical, oval-shaped, geological structural depression (Emmons and others, 1896). This structural basin lies immediately east of the Front Range and covers a large part of eastern Colorado north of Pueblo, southeastern Wyoming, and southwestern Nebraska. The western part of the quadrangle is made up of the rugged, high-relief topography of the Rampart Range, which trends north-south for over forty miles from Colorado Springs to Kassler. Most of this mountainous region is forested land administered by the U.S. Forest Service.

The exposed bedrock in the mountainous region of the Larkspur quadrangle consists primarily of granite of the Mesoproterozoic Pikes Peak batholith. Sedimentary rocks of Paleozoic and Mesozoic age crop out in the northwestern part of the quadrangle in close proximity to the mountain front. The "Great Unconformity," a nonconformity where the Cambrian Sawatch Sandstone lies directly upon the Precambrian granite basement, is spectacularly exposed in the northwestern quarter of the quadrangle along Gove Creek on the Sandstone Ranch. Faulting is generally responsible for the juxtaposition of rocks of Paleozoic through Tertiary age adjacent to Proterozoic rocks along the mountain front. The dominant fault is the Rampart Range fault which generally strikes north-south through the central and south-central parts of the quadrangle. The Rampart Range fault bifurcates or is joined by an additional north-south striking fault that is concealed in the north central part of the quadrangle. This fault was originally mapped in the Dawson Butte quadrangle to the north (Morgan and others, 2004) and is referred to as the West Plum Creek fault. The Perry Park fault strikes north-south in the extreme northwestern part of the quadrangle. Both the Rampart Range fault and the Perry Park fault have field relations suggestive of high-angle reverse faults dipping to the west. The concealed nature of the West Plum Creek fault makes its geometry more difficult to determine, however, field relations in the Dawson Butte quadrangle also suggest that it is of a high-angle reverse nature.

The exposed bedrock in the eastern half of the Larkspur quadrangle consists primarily of the assemblage of lithologies shown on the geologic map as the Denver Formation (Tkd) and Dawson Arkose (Tda). At the time of deposition of these units in the quadrangle, during the Paleocene and Eocene Epochs (about 65 to 50 million years ago), the uplift of the Front Range was well underway. Braided streams were delivering to the basin a mixture of gravel, sand, silt and clay derived from weathering and erosion of that uplifted area. The source of those granitic arkosic materials was mostly the Precambrian Pikes Peak Granite, located immediately to the west of the Rampart Range mountain-front fault system. Stream flow was generally towards the east (Morse, 1979; Crifasi, 1992). The pebble conglomerate and arkosic sand beds of the Denver and Dawson formations are cross bedded and fill broad channels generally cut into finer-grained deposits of clayey sandstones and sandy claystones. Interbedded between the coarse-grained beds are finer-grained and thinner-bedded strata of light-gray to gray-green clayey sandstone and brown or brownish-gray sandy claystone occasionally containing fragments of organic material and plant fossils. The fine-grained parts of the Denver and Dawson formations were deposited by gentler currents in areas between the braided stream channels and probably were covered with vegetation.

Following the erosion of some of the upper part of the Dawson Arkose, the conglomerate of Larkspur Butte (Thorson, 2003b) was deposited in a series of channels and broad valleys occupied by streams which drained the newly rejuvenated mountains.   In the western part of the Greenland quadrangle the conglomerate of Larkspur Butte was deposited in narrowly confined, steep-walled stream valleys. These valleys became broader towards the east as in the Cherry Valley School and Castle Rock South quadrangles. The same eastward widening is apparent in the Castle Rock North quadrangle. Only a very small channel filled with conglomerate of Larkspur Butte was found in this quadrangle on the south side of Monkey Face Butte beneath the Wall Mountain Tuff. This channel is too small to show accurately on the geologic map, however.

The Wall Mountain Tuff, an ignimbrite or glowing hot volcanic ash flow, was erupted in the late Eocene and poured across the landscape. This ash flow blanketed the eroded surface of the Dawson Arkose and valleys which contained the conglomerate of Larkspur Butte. Because of its great heat, the ash compacted into a viscous plastic which flowed for short distances before it cooled into welded tuff.   In the northeast part of the Larkspur quadrangle erosional remnants of the Wall Mountain Tuff overlie the Dawson Arkose and a small channel filled with conglomerate of Larkspur Butte on Monkey Face butte.   The Castle Rock Conglomerate was deposited near the end of the Eocene in broad sheets on an erosion surface that cuts across the upper Dawson Arkose and Wall Mountain Tuff. Erosional remnants of the Castle Rock Conglomerate occur in the Greenland and Castle Rock South quadrangles adjacent to the Larkspur quadrangle, but none of the unit remains in the mapped area.

Since the deposition of the Eocene rocks, the area experienced continued periods of erosion and deposition. During the Miocene, the Ogallala Formation was deposited across much of eastern Colorado and possibly once covered the eastern part of this quadrangle but has since been removed by erosion. During the Quaternary, deposits of unconsolidated sands and gravels were left in paleochannels, former flood plains along stream courses, and on various upland erosion surfaces as streams eroded the landscape.

DESCRIPTION OF MAP UNITS

Geologic time divisions used in this report are shown in Figure 2. Numerical ages were taken from the United States Geological Survey Geologic Names Committee (2007) and the International Commission on Stratigraphy (2005).

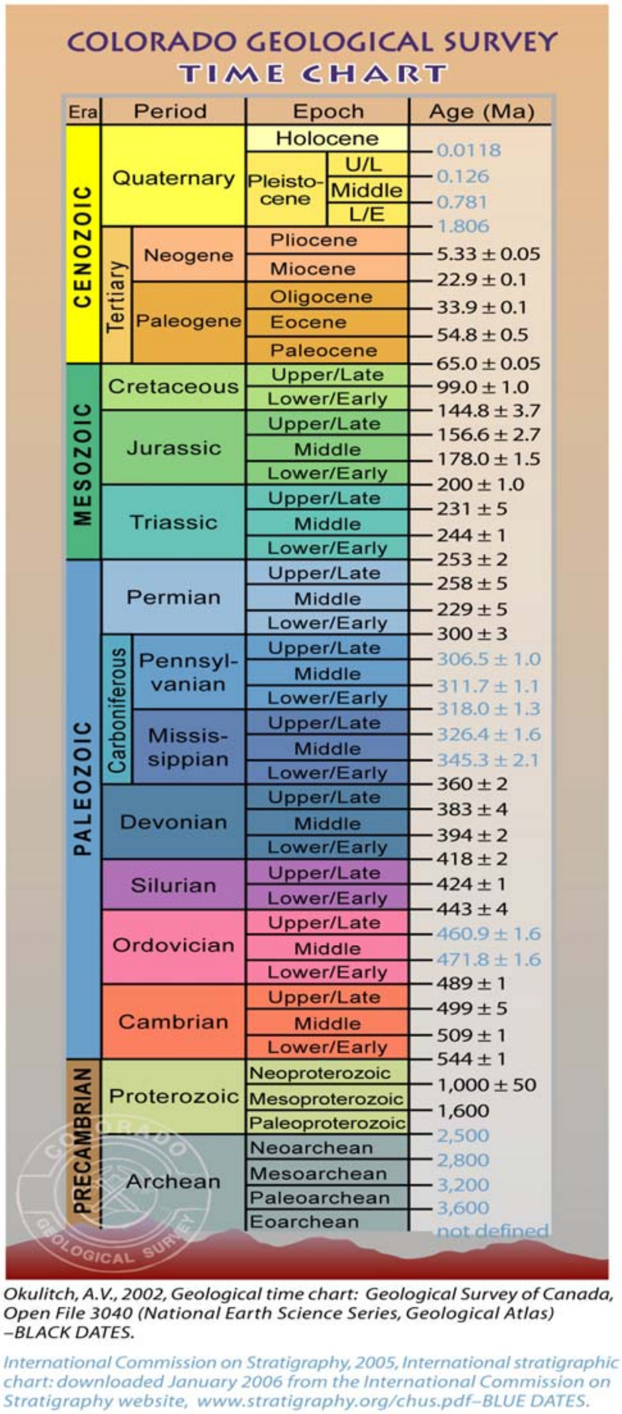


Figure 2. Geologic time chart used by the Colorado Geological Survey.

SURFICIAL DEPOSITS

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

af **Artificial fill (upper Holocene) —** Gravel, sand, silt, clay, and rock or concrete debris emplaced for constructing highways, railroads, dams, and other human-made structures. This category includes rock quarry waste in NW 1/4 sec. 32, T. 10 S., R. 67 W. Thickness generally is between 5 and 50 ft.

ALLUVIAL DEPOSITS — Sand, silt, gravel, and clay transported and deposited by flowing water in channels or as unconfined runoff. The alluvial deposits in the Larkspur quadrangle are predominantly composed of quartz, feldspar, and granite fragments derived from arkosic source materials in the Denver Formation and Dawson Arkose, and from the Pikes Peak Granite. Most of the fragments in the channel and flood-plain (Qa) and terrace (Qt_1, Qt_2, Qt_3) deposits are subrounded coarse pebbles (less than 1.25 inches) or smaller grains. Larger pebbles and small cobbles (up to about 4 inches) of well rounded light-colored quartz and larger cobbles and small boulders of rounded to subrounded dark-pink to light-red Pikes Peak Granite are common.

Part of the Larkspur quadrangle is mantled by older alluvial deposits of probable Pleistocene or even upper Pliocene age (Qp_1, Qp_2, Qp_3, Qp_4). The relative age of these deposits has been interpreted from the degree of inclination of the upper surfaces, height above base level, and position in the landscape. These deposits have been grouped together as “older alluvium” because they represent higher elevations of the present drainage system. The youngest of these older alluvial deposits, Qp_1, has surfaces that mimic the present drainage system but represent material deposited during a higher base level of the drainage than present. The locations and trend of remnants of older alluvial deposits (Qp_2, Qp_3, Qp_4) at even higher elevations in the landscape than Qp_1 suggest that these deposits are remnants of older drainage channels of the current drainage system.

Qa **Channel and flood-plain alluvium (upper Holocene) —** Pale-brown to brown sand, gravel, silt, and minor clay underlying narrow flood plains, stream channels, and, locally, low terraces flanking flood plains. Unit is generally coarser, lighter in color, and more poorly sorted than unit Qt_1. In many places, the unit is so young that plant roots have scarcely disturbed or destroyed stratification that extends nearly to the ground surface. Typically no soil profile or a weak A-C profile has developed. Unit is subject to frequent flooding. Estimated thickness is 3-7 ft.

Qt_1 **Terrace alluvium one (Holocene and upper Pleistocene) —** Pale-brown and brown to grayish-brown beds of sand, silty fine sand, sandy silt, clayey silt, and gravel. Generally, stratification is weakly expressed, and texture and composition vary along the valley axis. The upper surface of the unit is 3-10 ft higher than some of the larger streams but is only about 2-5 ft higher than the smaller streams of the area. Infrequent large floods may inundate Qt_1 in places. The unit may correlate with the post-Piney Creek Alluvium of Maberry and Lindvall (1972) and the post-Piney Creek and Piney Creek alluvium of Trimble and Machette (1979a). Thickness is estimated to be 5-15 ft.

Qt_2 **Terrace alluvium two (upper Pleistocene) —** Very pale-brown to dark-grayish-brown, extremely poorly sorted sand and subordinate amounts of gravel. Where perennial streams such as Plum Creek emerge from the mountain front, the unit may contain basal channel boulders up to 80 cm in size. The unit appears to correlate with the Piney Creek Alluvium of Maberry and Lindvall (1972) and may correlate with the Broadway alluvium of Trimble and Machette (1979a). The upper surface of the unit is typically 5-25 ft higher than the larger streams. Thickness is 5-20 ft.

Qt_3 **Terrace alluvium three (upper middle Pleistocene) —** Chiefly pale-brown to light grayish-brown, extremely poorly sorted sand, gravel, and cobbly or bouldery gravel that underlies terrace remnants along the larger streams of the area. The upper surface of the unit is 20-40 ft higher than the drainages. The unit may correlate with the Louviers Alluvium of Maberry and Lindvall (1972, 1977), Scott (1962, 1963a), and Trimble and Machette (1979a). Estimated thickness is 5-30 ft.

Qau **Alluvium, undivided (Holocene and Pleistocene) —** Chiefly pale-brown to brown, poorly sorted sand and fine gravel in valley heads in the upper parts of drainages and small areas of valley fills in the Rampart Range. The unit includes sheetwash and stream-deposited alluvium that are undivided. Reasons for not differentiating these deposits include: (1) different ages of alluvium may be superposed but incision has not differentiated them by elevation, (2) exposures are poor, (3) two or more units are present but are too small to show separately at the map scale, and (4) access is difficult of impossible. These alluvium-filled valley heads are not exhumed or deeply incised. The unit probably includes sediment that is correlative with units Qa, Qt_1, and possibly Qt_2. Estimated thickness is 3-20 ft.

Qsw **Sheetwash (Holocene and upper Pleistocene) —** Typically, light-grayish-brown, pale-brown, to brown, extremely poorly sorted sand, silty and clayey sand, and minor amounts of gravel including some cobbles and small boulders. Unit consists chiefly of material transported on moderate slopes by sheet flow but also includes some sediment delivered by runoff in rills and minor gullies. The abundance of sand-size grains and pebbles in this unit make it a grus-like deposit. The unit has been largely derived from disintegration of the Denver

Formation and Dawson Arkose in the eastern half of the quadrangle, but near the mountain front in the northwestern part of the quadrangle, it is derived from erosion of Fountain Formation, Pikes Peak Granite, and from older alluvial deposits. In the Perry Park, Haystack Ranch, and Sandstone Ranch areas this unit forms valley fills that have infilled against presumed late-glacial Qt_2 main-channel terraces. Estimated thickness is 3-20 ft.

Qf_1 **Alluvial-fan deposit one (Holocene and upper (?) Pleistocene) —** Typically, light grayish-brown, pale-brown, to brown very poorly sorted sand, silt, gravel, and occasional coarser fragments as large as boulder size, deposited by streams on fans at the edges of valley floors and around Raspberry and Monkey Face Buttes in the eastern part of the quadrangle. The unit is composed of material that was deposited by a combination of debris-flow and mud-flow processes in shifting channels on steep slopes as well as by sheet-flow processes. The fan-shaped geomorphic form of these deposits allows them to be mapped separately. Estimated thickness is 3-50 ft.

Qf_2 **Alluvial-fan deposit two (upper (?) Pleistocene) —** Around Raspberry Butte, this unit consists of grus-like deposits predominantly composed of quartz and feldspar sand, granules and small pebbles from disintegrated Denver Formation and Dawson arkoses and also includes in some places boulders of well cemented arkose as large as 4 feet in diameter. Along the front of the Rampart Range in the northwestern part of the quadrangle, boulders more than five feet in diameter, apparently emplaced by debris flows, litter the heads of the fans. Unit has been mapped separately because it has been highly dissected by erosion and has lost most of its original alluvial fan geomorphic shape. Estimated thickness is from 0-100 ft.

Qf_3 **Alluvial-fan deposit three (upper (?) Pleistocene) —** This unit is only mapped along the mountain front in the northwestern part of the quadrangle. It consists of grus-like deposits predominantly composed of quartz and feldspar sand with small pebbles derived from Pikes Peak granite and the Fountain Formation. At the heads of the Qf_3 fans, the surface is littered with boulders up to ten feet in diameter apparently emplaced by debris flows. This unit has been mapped separately because it has been highly dissected by gully erosion so that it has lost completely its characteristic alluvial-fan geomorphic shape. No age information is available for the alluvial fan units and no attempt is made to correlate these units to alluvial fans in other areas. Based on geomorphic relationships, however, units Qf_1, Qf_2 and Qf_3 must post date, that is, be younger than, deposition and subsequent erosion of units Qp_1-Qp_4 in this area.

Qf **Alluvial-fan deposit, undivided (Holocene to upper (?) Pleistocene) —** Pale brown to brown, moderately sorted, matrix-supported, gravelly sand to gravelly silt; to clast-supported, pebble and cobble gravel in a sandy silt or silty sand matrix. Clasts are mostly subangular to well rounded and typically composed of Pikes Peak Granite. Approximate age and relation to other alluvial units is unknown. The unit is composed of material that was deposited by a combination of debris-flow and mud-flow processes in shifting channels on steep slopes as well as by sheet-flow and alluvial processes. Deposit is locally dissected and soil development is highly variable. The maximum estimated thickness locally exceeds 25 feet. Areas mapped as alluvial fans are subject to future flooding and debris-flow events.

Qp_1 **Older alluvium one (Pleistocene) —** Chiefly light-brown to light-reddish-brown, extremely poorly sorted sand and coarse gravel, which, in places, includes boulders as well as pebbles and cobbles. In the eastern part of the map, the unit has cobbly and bouldery layers with angular to subround fragments of Wall Mountain Tuff, subrounded clasts of Denver Formation or Dawson arkose, and in places abundant well rounded cobbles and small bounders of granite, gneiss, and quartzite weathered out of the Castle Rock Conglomerate. Near Gove Creek in the northwestern part of the quadrangle, one small remnant is a cobbly channel deposit of mixed lithology with clast of Fountain Formation and sand and fine gravel derived from Pike's Peak Granite. This unit may correlate with the Slocum Alluvium of Maberry and Lindvall (1972) but may include some material that they would have been mapped as Louviers Alluvium at lower elevations. The unit may also correlate with the Slocum Alluvium of Trimble and Machette (1979a) and Bryant and others (1981). Unit Qp_1 is poorly exposed; estimated thickness may be as great as 60 ft.

Qp_2 **Older alluvium two (Pleistocene) —** In the eastern half of the quadrangle, this deposit is composed of light-brown sand and fine gravel that is derived from the Denver and Dawson formations, plus cobbles and small boulders of arkose from the same formations, Wall Mountain Tuff, and well rounded pebbles or cobbles of Pikes Peak granite, gneiss, and quartzite. Qp_2 is predominantly a gravel and small pebble unit but contains more cobbles and larger cobbles in locations close to the mountain front where the bedrock is Pikes Peak Granite. In the SW 1/4 sec. 20, T. 10 S., R. 67 W., the deposit contains small well-rounded boulders. In the northwestern part of the quadrangle near Plum and Gove creeks, several elongated remnants of gravelly to bouldery channel deposits of this unit cap gently sloping, flat-topped hills that are underlain by bedrock of the Fountain Formation. Clasts in the unit consist of Pikes Peak Granite, Fountain Formation Wall Mountain Tuff, and limestone and it is capped by a clayey weathering profile up to 3 m thick with high-chroma reddish brown colors. Unit Qp_2 may correlate with some of the deposits mapped as Verdos Alluvium by Trimble and Machette (1979a) and Bryant and others (1981) but also may include some deposits previously mapped as Rocky Flat Alluvium by them. Unit is about 5 to 100 ft thick.

Qp_3 **Older alluvium three (Pleistocene) —** Chiefly light-red to dark-pink pebbles and cobbles of Pikes Peak Granite with subordinate amounts of white quartz deposited as stream channel fill. Deposits of this unit are located at higher elevation than the deposits of Qp_2, so therefore Qp_3 is probably older. This ridge-capping deposit is an interesting illustration of inversion of topography where a Pleistocene stream channel now stands high as a ridge. This unit was mapped as Rocky Flat Alluvium by Trimble and Machette (1979a) and Bryant and others (1981) but its age is unknown and it could be older. Unit is about 5 to 40 ft thick.

Qp_4 **Older alluvium four (Pleistocene) —** Remnants of alluvial gravels composed predominantly of well rounded pebbles and cobbles of Pikes Peak Granite with subordinate amounts of white quartz, and occasional fragments of red quartzite or sandstone, preserved at high elevations in the Larkspur quadrangle. The unit includes the alluvial materials at the highest elevations in the quadrangle and it apparently represents the oldest stream channel deposits. Deposits of this unit in the south part of the map area were mapped as Verdos Alluvium by Trimble and Machette (1979a) but occur at much higher elevations than the rest of their Verdos or their Rocky Flats Alluvium. This unit therefore probably includes alluvial material that is older than Rocky Flats Alluvium, perhaps correlative with Nussbaum Alluvium or even older. Unit is about 5-30 ft thick.

MASS-WASTING DEPOSITS — Earth materials that were moved downslope under the principle influence of gravity. Colluvial deposits are the primary products of mass wasting in the Larkspur quadrangle. Colluvium, as used here, adheres in most respects to Hilgard’s (1892) definition. According to Hilgard, the principal attributes of colluvium is that it (1) was derived locally and transported only short distances, (2) may contain clasts of any size, (3) has no structures or stratification indicative of sedimentation by water flowing in channels, and (4) has an areal distribution that bears no relation to channelized flow of water. Minor amounts of sheetwash alluvium may be included.

Qc **Colluvium (Holocene to upper Pleistocene) —** Unit comprises slope deposits that consist chiefly of very pale-brown to brown sand and fine gravel plus cobbles and boulders of Denver or Dawson formation arkose, and Wall Mountain Tuff. Deposits typically are massive and very poorly sorted to extremely poorly sorted. Unit is estimated to be 2-100 ft thick.

EOLIAN DEPOSITS — Wind-deposited sediment.

Qes **Eolian sand (Holocene to upper Pleistocene) —** Very pale-brown, pale-brown, and light grayish-brown sand. Unit is predominantly fine- to medium-grained sand that appears to have been blown out of the East Plum Creek drainage and deposited on top of the Qp_1 alluvial unit. Thickness is estimated to be 3-15 ft.

BEDROCK UNITS

Twm **Wall Mountain Tuff (late Eocene)** — The Wall Mountain Tuff is a moderately to densely welded tuff of rhyolitic composition (Izett and others, 1969; Epis and Chapin, 1974). It is generally light- to medium-brown colored when fresh but is occasionally medium-gray colored in a few of the more densely welded outcrops. On weathering, the tuff may be light brown, lavender, pink, reddish brown, or maroon. The fine-grained groundmass usually contains small phenocrysts of biotite and sanidine, and occasionally near the base may contain quartz grains and small arkose fragments ripped up from the underlying strata. The Wall Mountain Tuff was emplaced in the Castle Rock area as an ash-flow that was hot enough that the ash compacted and welded into a viscous plastic-like consistency after emplacement. In places, the welded ash flowed and developed flow banding before cooling and solidifying.

The Wall Mountain Tuff has been dated as about 36.7 million years in age by McIntosh and others (1992) and McIntosh and Chapin (1994). The ash flow eruption which deposited the Wall Mountain Tuff has been considered in the past to be an Oligocene event (for example see Trimble and Machette, 1979a). However, the age for the end of the Eocene is now recognized to be 33.7 mybp (Remane and others, 2002), so the Wall Mountain Tuff should now be considered to be late Eocene.

The Wall Mountain ash-flow was erupted from an unidentified location west of the upper Arkansas River valley between Salida and Buena Vista (Epis and Chapin, 1974). The Wall Mountain Tuff is about 30 ft thick in the two erosional remnants in the quadrangle on Monkey Face and Raspberry Buttes where it rests predominantly on older deposits of Dawson Arkose. On the south side of Monkey Face butte (SW 1/4 sec. 33, T. 9 S., R. 67 W.) the Wall Mountain Tuff was deposited across a small channel, incised in Dawson Arkose and filled with conglomerate of Larkspur Butte, a relationship that is too small to show accurately on the geologic map.

Tlc **Conglomerate of Larkspur Butte (late? Eocene)** — The conglomerate of Larkspur Butte (Thorson, 2003b) is a newly recognized unit that underlies the late Eocene Wall Mountain Tuff on Larkspur Butte and on many of the high buttes in the Greenland (Thorson, 2003b), Black Forest (Thorson, 2003a), Cherry Valley School (Thorson, 2004b), and Castle Rock South (Thorson, 2004a) quadrangles. The conglomerate of Larkspur Butte is a brown, pinkish-brown, or pink arkosic conglomerate composed predominantly of pebbles and cobbles of pink granite or pink feldspar in a coarse sand-size to small-pebble matrix of quartz and pink feldspar. Clasts of gray or white quartz are common; less abundant are clasts of gneissic metamorphic rocks, quartzite, red sandstone, and chert; clasts are subround to round. The conglomerate of Larkspur Butte is distinguished from the underlying Dawson Arkose by its coarser grain size, pinkish color tones, dominance of pink granite and unbleached pink feldspar grains, and lack of clay in the matrix material. The uppermost strata of the Dawson are generally very light colored (white, cream, light greenish-gray) because most of the feldspar in the Dawson Arkose is bleached and essentially all of the macroscopic pores of the Dawson beds are filled with light-colored clay. The bleaching and clay-filling in the Dawson suggests a prolonged period of weathering and/or diagenetic alteration of the Dawson before deposition of the conglomerate of Larkspur Butte. The conglomerate of Larkspur Butte is similar in appearance to the Castle Rock Conglomerate although the latter generally lacks pink tones and is light gray in color. The principal distinguishing characteristic is the fragments of Wall Mountain Tuff in the Castle Rock Conglomerate. In the absence of tuff fragments, the two late-Eocene conglomerates may be very hard to distinguish. The only deposit of conglomerate of Larkspur Butte in the Larkspur quadrangle is a small channel fill, up to 10 ft thick and about 100 ft long, exposed on the south side of Monkey Face beneath the Wall Mountain Tuff. Because of its small size, and the steep topography in its outcrop area, this deposit cannot be shown accurately on the geologic map. Its description and occurrence is recorded here since the unit is newly described (Thorson, 2003b) and represents a previously undocumented part of the Tertiary history of the Front Range area.

A late Eocene age is indicated because the conglomerate of Larkspur Butte fills, or partially fills, paleovalleys that were present in the late Eocene and appear to have influenced the deposition of the late Eocene Wall Mountain Tuff.

Dawson Arkose and Dawson Formation (Eocene to Upper Cretaceous) — A short discussion of these rock units is useful here, as many nomenclature schemes have been applied by various authors. The names we use for this map are the result of many years of mapping these units (fig. 1). A complete review of the nomenclature and its history is being prepared as part of a compilation of the geological mapping done by the Colorado Geological Survey in the area between Colorado Springs and Denver (Thorson, 2008, in preparation). Further revisions in nomenclature are discussed in that work.

The Dawson Formation is divided into upper and lower parts in the Colorado Springs area (Thorson and others, 2001, Thorson and Madole, 2002). The lower part is entirely Upper Cretaceous in age and composed almost exclusively of andesitic debris. The upper part of the Dawson Formation is a mixture of andesitic and arkosic material deposited during the Late Cretaceous and early Tertiary. The upper part of the Dawson Formation is divided into facies unit one ($TKda_1$), facies unit two ($TKda_2$), facies unit three ($TKda_3$), facies unit four ($TKda_4$), and facies unit five ($TKda_5$). These facies units are differentiated on the relative proportions of andesitic and arkosic material, on the thickness and style of coarse-grained bedding units, and on the relative proportion of fine-grained claystone and siltstone versus coarser-grained beds of sandstone, arkose, pebbly arkose, and pebble conglomerate.

In the Denver area, and extending into Larkspur quadrangle, the nomenclature for the comparable Upper Cretaceous to Eocene strata mapped as Dawson Formation in the Colorado Springs area is quite variable. Maberry and Lindvall (1972, 1977) used Dawson Arkose and Denver Formation, with the Dawson Arkose younger than, and stratigraphically superior to, the Denver Formation. Trimble and Machette (1979b) changed terminology and used “Dawson and Arapahoe Formations” and “Denver Formation” of comparable Paleocene to Upper Cretaceous age. Bryant and others (1981) used Arapahoe Formation and restricted this unit to Upper Cretaceous age, while Dawson Arkose and Denver Formation were retained. On the map of Bryant and others (1981), the Dawson Arkose is designated as Eocene, Paleocene, and Upper Cretaceous, the Denver Formation is described as Paleocene and Upper Cretaceous, and the formations are shown as interfingering lateral equivalents of each other.

Recent compilation across the entire 1999 through 2007 CGS mapping program has determined that facies unit 4 (TKda4), used in a preliminary version of the geologic map of the east half of the Larkspur quadrangle (Thorson, 2005b) is equivalent to the Denver Formation as used by Scott (1962, 1963b) and Maberry and Lindvall (1972, 1977) in the southern part of the Denver metropolitan area. Facies unit five (TKda5) and facies unit six ($TKda_6$) of the Dawson Formation, also used on the preliminary map of the Larkspur quadrangle (Thorson, 2005b), are now recognized to be equivalent to the Dawson Arkose as used by Maberry and Lindvall (1972, 1977) and Trimble and Machette (1979b).

In an attempt to simplify the nomenclature confusion, Raynolds (2002) defined two unconformity bounded sequences, D1 and D2, whose boundary is approximately the regional paleosol of Soister and Tschudy (1978). The D2 sequence contains Maberry and Lindvall’s (1972, 1977) Dawson Arkose, above the regional Denver Basin paleosol, but only part of Bryant and others (1981) Dawson Arkose. All of the rest of the Upper Cretaceous through Paleocene strata of the Denver Basin are included within the D1 sequence. The recognition of the D1 and D2 sequences is a very useful addition to the understanding of the depositional sequence of Upper Cretaceous through Eocene strata in the Denver Basin, and has been widely adopted (Raynolds and Johnson, 2002; Raynolds, 2002; Nichols and Fleming, 2002; Obradovich, 2002; Wilson, 2002; Farnham and Kraus, 2002; Kelley (2002); Kelley and Blackwell, 2002; Woodward and others, 2002; Carpenter and Young, 2002; Hicks and others, 2003; Wheeler and Michalski, 2003; Barclay and others, 2003; Ellis and others 2003; Johnson and others, 2003; Hutchinson and Holroyd, 2003; Eberle, 2003; Raynolds and Johnson, 2003).

However, paleontological control is necessary for the recognition and application of the D1-D2 nomenclature. Recent mapping along the west side of the Denver Basin (Thorson and Madole, 2002; Thorson, 2003a, 2005b; Morgan and others, 2004) has shown that there are multiple paleosol horizons in the Dawson Formation and that no single paleosol exposure clearly defines the D1-D2 boundary without confirmation. Nonetheless, the Dawson Arkose of this report appears to be consistently equivalent to Raynolds' D2 sequence.

Logs and samples from the Dawson in the abandoned petroleum test well in the Greenland quadrangle (sec 17, T. 10 S., R. 66 W.; F.G. Holl et al., #1 Greenland Cattle Co.), plus the thickness of Dawson exposed on the adjacent buttes above the collar of the well, indicate that the Dawson Formation is about 2,750 feet thick in that quadrangle.

Tda **Dawson Arkose (middle? to early Eocene)** — The Dawson Arkose is dominated by very thick-bedded to massive, cross-bedded, light-colored arkoses, pebbly arkoses, and arkosic pebble conglomerate, but also the unit 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 in the finer-grained parts. The Dawson Arkose also contains a few massive structureless beds interpreted to be mudflows and common beds of greenish-gray to olive-green sandy claystone. Occasionally the unit contains thin, poorly developed, red, pink, and yellow-brown oxidized zones interbedded with, or developed within, the thick arkoses. Some of these oxidized zones have preserved mottling, burrows, and root structures which indicate their origin as paleosols; others are probably just the result of oxidation by groundwater. The Dawson Arkose is at least 400 ft thick in the quadrangle but the top of the unit has been removed by erosion in most places. The Dawson Arkose appears to correlate with most of Raynolds' (2002) D2 sequence and with the Dawson Arkose of Maberry and Lindvall (1972, 1977) but does not correlate specifically with any of the units used by Bryant and others (1981).

The Dawson Arkose 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 can be well indurated and may require considerable effort to excavate. The clay content of the finer-grained parts of the facies unit suggests that soils developed from the Dawson may have high swell factors. Rock fall from cliffs in the Dawson Arkose poses a possible slope-stability hazard in some areas. The unit appears to be equivalent to the Dawson Arkose and/or Dawson aquifer in the Denver area (George VanSlyke, 2001, oral commun.).

TKd **Denver Formation (early Paleocene) —** The Denver Formation is dominated by greenish-gray to light-gray sandy claystone and clayey sandstone but contains beds of white to light-tan, fine- to medium-grained, feldspathic cross-bedded friable sandstone similar to those in the Dawson Arkose. The sandstones are poorly sorted, have high clay contents, and are commonly thin or medium bedded; wavy bedding and ripple cross-laminations are also common. Thickness of the Denver Formation in the quadrangle is estimated to be greater than 300 feet.

Close to the fault boundaries between the Denver Formation and older rocks, the Denver Formation contains more frequent and coarser beds that resemble the thick arkose or feldspathic sandstone beds of the Dawson Arkose. These thicker, coarser, and more feldspathic beds appear to represent the deposits of higher energy streams near the original western margin of the Denver Basin. Further to the north, in the western edge of the Denver metropolitan area, such coarse, basin margin deposits have been mapped as a basal unit of the Denver stratigraphy, the Arapahoe Formation (Trimble and Machette, 1979b, Bryant and others, 1981). Here in the Larkspur quadrangle, where the edge of the Denver Formation is a fault instead of a conformable contact, and it is apparent that we don’t see the original basin margin because no Arapahoe Formation is recognized at the surface.

In the Monument quadrangle (Thorson and Madole, 2002), the Dawson Butte quadrangle (Morgan and others, 2004), Castle Rock South quadrangle (Thorson, 2004a), Castle Rock North quadrangle (Thorson, 2005) the top of facies unit Tkda4 (equivalent to the top of the Denver Formation in the Larkspur quadrangle) is marked by a strongly developed paleosol that was traced around the Denver Basin by Soister and Tschudy (1978). This Denver Basin paleosol has been studied extensively by Farnham and Kraus (2002) and Nichols and Fleming, (2002), and it is widely used as the approximate boundary between Paleocene and Eocene strata (see, for example Raynolds, 2002; and Raynolds and Johnson, 2003). A similarly well developed paleosol is well exposed near the south edge of the quadrangle, east of Palmer Lake. A poorly exposed paleosol, which may be the Denver Basin Paleosol of Soister and Tschudy (1978), occurs along Highway 105 (Perry Park Road) near the south edge of sec. 17, T. 10 S., R. 67 W. Other poorly exposed paleosols occur within the Denver Formation near the north edge of the quadrangle. Here a note of caution must be again sounded; in the Dawson Butte quadrangle (Morgan and others, 2004), Black Forest quadrangle (Thorson, 2003a), and Monument quadrangle (Thorson and Madole, 2002), multiple paleosol horizons have been documented. Only one of these can be the “Denver Basin Paleosol” of Soister and Tschudy (1978), so paleontological confirmation is necessary before confidently using a paleosol occurrence as a distinctive time marker.

The Denver Formation spans the Cretaceous-Paleogene (K-P) boundary, but the exact location of the time boundary in most of the basin has not been identified. Kluth and Nelson (1988) reconfirmed the Late Cretaceous (late Maastrichtian) age for the upper part of the Dawson Formation on the U.S. Air Force Academy. In the Elsmere quadrangle, the K-P boundary has been approximately located about 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, Johnson and others, 2003). Brown (1943) determined the location of the Cretaceous – Tertiary boundary at South Table Mountain, about 35 miles north of the Larkspur quadrangle. Paleocene fossil leaf localities occur in the Monument quadrangle (Scotty’s Palm, Denver Museum of Nature & Science, DMNH-1204, NE 1/4 SW 1/4 sec. 12, T. 12 S., R. 67 W., Johnson, 2001, Johnson and others, 2003; and Baptist Road, Denver Museum of Nature & Science, DMNH-2177, NW 1/4 sec. 35. T. 11 S., R. 67 W., Johnson and Raynolds, 1998; Johnson and others, 2003). An important early Paleocene rain forest fossil leaf locality, estimated to be 63.8 ± 0.3 mybp (million years before present), is located in the Castle Rock North quadrangle in NE 1/4, SW 1/4, sec. 2, T. 8 S., R. 67 W. (Johnson and Ellis, 2002; Ellis and others, 2003; Johnson and others, 2003). This site is estimated to be 284 m above the K-P boundary on the basis of correlations with the Castle Pines cored well located in the adjacent Sedalia quadrangle (Ellis and others, 2003, figure 2). The rain forest fossil locality is estimated to lie just below the Denver Basin paleosol, a regional paleosol traced around the basin by Soister and Tschudy (1978) and proposed to mark the Paleocene-Eocene boundary. Recent work on this paleosol has recognized that it separates early Paleocene pollen zone P3 from late Paleocene pollen zone P6 (Nichols and Fleming, 2002) and lies just below the Paleocene-Eocene boundary. A prominent paleosol thought to be the Denver Basin paleosol was used as the boundary between Dawson Formation facies units four and five in the Monument quadrangle (Thorson and Madole, 2002). Mapping of the Castle Rock South (Thorson, 2004a) and Castle Rock North (Thorson, 2005a) quadrangles has shown that most of the local Dawson Formation lies above a well developed paleosol thought to be the Denver Basin paleosol and is therefore correlated with the Eocene TKda5 facies unit (Dawson Arkose) of the Monument quadrangle. However, Morgan and others (2004) have confirmed the observation that there are multiple paleosols developed in the Dawson Formation along the western edge of the Denver Basin (Thorson and Madole, 2002; Thorson, 2003a), so appropriate caution is advised in using the relation of a stratigraphic unit to any particular paleosol as an indication of age.

Paleosol outcrops thought to be the Denver Basin regional paleosol marking the approximate boundary between Paleocene and Eocene strata were found in the east half of the Larkspur quadrangle northeast of Palmer Lake (NW 1/4, sec. 4, T. 11 S., R. 67 W.) and along Highway 105 (Perry Park Road, south edge sec. 17, T. 10 S., R. 67 W.). These paleosol occurrences and the regional paleontological control suggest that the Denver Formation in the Larkspur quadrangle should be assigned to the Paleocene. The Dawson Arkose is considered to be Eocene. In the north part of the map area several paleosol occurrences were found within the Denver Formation, however. Two of these are shown in sec. 20, T. 9 S., R. 67 W. The occurrence of paleosol horizons at multiple levels within the Denver Formation in this quadrangle, as well as equivalent strata in the Monument (Thorson and Madole, 2002), Black Forest (Thorson, 2003a), and Dawson Butte (Morgan and others, 2004) quadrangles, requires a reiteration of the caution that the presence of a paleosol exposure does not necessarily signify the approximate Paleocene - Eocene boundary. Appropriate caution and paleontological control is recommended.

The Denver Formation appears to correlate with most of Raynolds' (2002) D1 sequence and with the Denver Formation of Maberry and Lindvall (1972, 1977), but does not correlate specifically with any of the units used by Bryant and others (1981). Neither the base of the Denver Formation nor the lower facies units of the Dawson Formation are exposed in the Larkspur quadrangle.

The Denver Formation is quite variable in permeability but usually well drained at the surface. It appears to have good foundation characteristics, but the greenish-gray and olive-green claystone beds have high swell factors, being apparently rich in montmorillonitic clays. Soils developed from this unit may have very high swelling characteristics. It is common practice in subdivision construction in the southern part of the Denver metropolitan area to excavate areas of Denver Formation with high swell factors from around proposed foundations and replace the material with sandy fill of lower swell factor and better drainage permeability. However, caution is advised to make sure that appropriate measures have been taken to accommodate swelling soils and heaving bedrock, particularly in areas of the Denver Formation.

TKdu **Dawson Formation, undivided (Eocene to Upper Cretaceous) —** Undivided Dawson Formation possibly including facies units one through facies unit three of the upper Dawson plus the exposed Denver Formation and Dawson Arkose; shown only on cross section.

Kl **Laramie Formation (Upper Cretaceous) —** The Laramie Formation does not crop out in the Larkspur quadrangle and is shown in cross section only. In the

Dawson Butte quadrangle to the north, the formation is a fine to medium grained, bleached white to cream colored sandstone, composed of well sorted, rounded to subrounded, quartz grains with a thickness of 470 ft. (Morgan and others, 2004).

Kf **Fox Hills Sandstone (Upper Cretaceous) —** The Fox Hills Sandstone does not crop out in the Larkspur quadrangle and is shown in cross section only. In the Dawson Butte quadrangle to the north, the formation is a dark brown, medium to fine-grained sandstone approximately 300 ft. thick (Morgan and others, 2004).

Kp **Pierre Shale (Upper Cretaceous) —** Outcrops of Pierre Shale are not well exposed at the surface in the Larkspur quadrangle, however the formation is mapped in a fault wedge in the NE ¼ of the quadrangle along the eastern boundary of R 68 W and the western boundary of R 67 W. At this location black, gray, and pea green soils derived from the Pierre Shale are observed. Fossils have been found at a location in the NW ¼ of the NW ¼ of sec. 31, T. 9 S., R. 67 W. and identified by William Cobban as the ammonite *Baculites clinolobatus*, a guide fossil for the upper transition zone of the Pierre Shale (Dave Noe, oral commun., 2007). Where exposed to the south near Colorado Springs, the shale is a dark gray to black, extremely fissile, highly fractured shale of marine origin. It weathers to a soft, friable talus and becomes distinctly light gray, olive green, and pea green in color. The formation is over 6,000 feet thick in the Dawson Butte quadrangle (Morgan and others, 2004).

Kn **Niobrara Formation (Upper Cretaceous) —** The Niobrara Formation in this region consists of two members of marine origin; the Smoky Hill Shale Member, and the underlying Fort Hayes Limestone Member. Weathering characteristics between the two members of the Niobrara Formation are distinctive with the Fort Hayes Member commonly supporting a low hogback and the Smoky Hill Member underlying valleys marked by soils containing light-gray and buff shale chips. Berman and others (1980) noted that in Colorado the contact of the Niobrara Formation with the overlying Pierre Shale is generally conformable and transitional from shaley chalk beds of the Smoky Hill Member to slightly calcareous silty shale beds of the Pierre Shale. The Smoky Hill Shale Member is made up of soft, light- to dark-gray, yellowish-orange, and brown, thin-bedded and laminated, limey shale and local thin beds of slightly resistant, gray and white chalk and limestone. The Niobrara Formation is observed at only one location in the Larkspur quadrangle; in the SW ¼ of sec. 6 of T. 10 S., R. 67 W. where the Smoky Hill Member is interpreted to be in the hanging wall block of the West Plum Creek fault splay. The thickness of the Smoky Hill Shale Member is 338 feet in the Dawson Butte quadrangle (Morgan and others, 2004).

Kcg **Carlile Shale, Greenhorn Limestone, and Graneros Shale, undivided (Upper Cretaceous) —** The Carlile Shale, Greenhorn Limestone, and Graneros Shale sequence does not crop out in the Larkspur quadrangle and is shown in cross section only. In the Dawson Butte quadrangle to the north, this undivided sequence of marine units has a combined thickness of 370 ft. (Morgan and others, 2004).

Kd **Dakota Sandstone (Lower Cretaceous) —** The Dakota Sandstone crops out at only one location in the north central part of the Larkspur quadrangle where it consists of interbedded buff, yellow, and gray, well sorted quartz sandstone and gray shale beds. The unit locally contains ironstone concretions, ripple marks, and cross beds. The formation is interpreted as a shoreline regressive sequence (Weimer, 1970) and is about 156 feet thick in the Dawson Butte quadrangle (Morgan and others, 2004).

Kpu **Purgatoire Formation (Lower Cretaceous) —** The Purgatoire Formation consists of the Glencairn Shale Member and underlying Lytle Sandstone Member and does not crop out in the Larkspur quadrangle and is shown in cross section only. In the Dawson Butte quadrangle to the north, the formation is just over 100 ft. in thickness (Morgan and others, 2004).

Jmr **Morrison Formation and Ralston Creek Formation, undivided (Upper Jurassic) —** The Morrison Formation consists of soft, variegated claystone and mudstone beds containing thin beds of marl, limestone, sandstone, and minor conglomerate. Multiple colors include pale green, red, purple, white, tan, and light gray. More resistant sandstone beds and the distinct maroon weathering increase in frequency towards the top of the formation. The underlying Ralston Creek Formation consists of mostly soft, thin-bedded, gray and red sandstone, siltstone, and shale. Massive gypsum beds within the Ralston Creek Formation range in thickness from 20 to 80 feet. The combined thickness of the Morrison Formation and Ralston Creek Formation is approximately 600 feet thick in the Dawson Butte quadrangle (Morgan and others, 2004) and both formations are continental in origin.

ꞦPl **Lykins Formation (Lower Triassic? and Upper Permian) —** The Lykins Formation is a soft to moderately resistant, thin-bedded, reddish-brown, light-tan, to light-gray, sandy siltstone and shale in a distinct clay matrix. Gypsiferous and anhydritic layers are common and the formation contains several prominent beds of light-gray to tan, stromatolitic dolostone beds. The carbonate beds exhibit a closely laminated texture indicative of algal mats from a shallow, hypersaline, marine environment. The contact with the underlying Lyons Formation is conformable and the thickness of the unit is 135 feet in the State

Lease # 1 well in sec. 16, T. 8 S., R. 67 W in the Dawson Butte quadrangle (Morgan and others, 2004).

Ply **Lyons Sandstone (Permian) —** Red, tan, and gray, cross-bedded, very well sorted, and fine grained quartz arenites, with minor isolated conglomerates. The Lyons Sandstone is composed almost entirely of frosted quartz grains, with calcite and hematite cement. The unit contains large scale planar cross bed sets throughout. It forms resistant vertical fins and hogbacks with precipitous cliffs in and around Perry Park. The lower contact is conformable with the Fountain Formation, and is reported by Grose (1990) to be a transitional contact, with "layers of channel sandstones and conglomerates." Total thickness of the Lyons is about 300 feet in the gently dipping hogbacks in the Perry Park subdivision in the northwestern part of the quadrangle. The formation becomes distinctively white to tan in color and more friable along the West Plum Creek fault in sec. 25 of T. 9 S., R. 68 W., possibly due to tectonic influence. The Lyons Sandstone was deposited in an aeolian environment, as evidenced by uniform grain size, frosted grain surfaces, and the presence of large scale asymptotic cross beds. Isolated conglomerates are interpreted to be interdune hardpan deposits.

PlPf **Fountain Formation and Glen Eyrie Formation, undivided (Lower Permian and Pennsylvanian) —** The Fountain Formation is composed of a complex package of pink, red, and less commonly white arkoses, with interbedded pebble to cobble conglomerate beds and maroon sandy and micaceous shales and siltstones. Fountain Formation arkoses are poorly sorted and composed of angular to subangular, very fine to very coarse sand grains and small pebbles, with isolated rounded to subrounded cobbles. Arkose composition is approximately 80% quartz, 20% potassium feldspar, with small amounts of muscovite and oxide grains in finer grained lithologies. Conglomeratic layers appear in lenses up to about 10 inches thick, with arkosic matrix. The isolated pebbles in the arkose and the thin conglomeratic lenses contain clasts of various compositions, primarily white and gray translucent quartz and Pikes Peak granite up to 4 inches in diameter. Malek-Aslani (1950) reported additional clast compositions, including red sandstone, chert, and limestone. The arkosic and conglomeratic deposits in the Fountain Formation show 4-inch to greater than 36-inch thick trough and planar cross bed sets. Fountain Formation shales and siltstones occur in discontinuous layers up to 20 inches or more in thickness, in various shades of brick red maroon and purple. The shales and siltstones contain muscovite flakes aligned parallel to bedding, and often contain small fining upward sequences of coarse to fine quartz and feldspar sand grains and lenses of arkose. The Fountain Formation weathers to a characteristic light pinkish red color, forming broadly rounded flatirons and rounded pinnacles and knobs. Shale and siltstone layers form recessed shelves on outcrops. The Fountain Formation is exposed along the mountain front throughout the northwestern part of the map area. Total Fountain Formation thickness is at least 2,000 feet thick in Perry Park. The actual total thickness, however, may be significantly greater; a complete unfaulted section of Fountain is not present in the map area. Suttner (1989) reports that the Fountain Formation likely formed as an alluvial fan and deltaic complex prograding off of the ancestral Front Range uplift. The Glen Eyrie Formation is composed of slightly fissile, rose-gray, silty claystones, with a few thin beds of sandstone. Malek-Aslani (1950) reports chert pebbles in the basal section. The Glen Eyrie Formation forms muddy red soils on the dip slope of the Williams Canyon Formation on the north bank of Bear Creek in the northwest corner of the mapped area. The Glen Eyrie rests disconformably on the Williams Canyon Formation. Total Glen Eyrie thickness is approximately 15 feet. Suttner (1989) interpreted the Glen Eyrie Formation as transitional between marine and non-marine environments.

Mwc **Williams Canyon Member of the Leadville Limestone (Mississippian) —** The Williams Canyon Member of the Leadville Limestone crops out along the mountain front in the northwestern part of the quadrangle. The member is comprised of thinly laminated intervals of micritic mudstones, and dense, wavy beds of gray, red, and purple dolomitic micrites that unconformably overlie the Manitou Formation. The basal part of the member is composed of a thin (< 1 foot) quartz sandstone that is medium to coarse grained, well rounded, and moderately sorted. At the top of the section, the unit is composed of pink and red, dolomite-cemented quartz sandstones composed of well rounded to subrounded medium- and coarse-grained quartz. The Leadville Limestone conformably overlies and may even interfinger with the Williams Canyon Member as reported several miles to the west in the Dakan Mountain quadrangle by Hill (1983) and Temple and others (2008) and in the northern part of the Mount Deception quadrangle (Temple and others, 2007). However, the Leadville Limestone is conspicuously absent in this quadrangle and others along the eastern flank of the Rampart Range. In some previously mapped quadrangles, the Colorado Geological Survey has mapped the Leadville Limestone and the Williams Canyon as an undifferentiated unit (MDlh, Hardscrabble Member of the Leadville Limestone (Mississippian) and the Williams Canyon Formation (Devonian). On the basis of detailed stratigraphic correlations and conodont identification by Hill (1983) throughout south-central Colorado, we have adopted the age and classification of the Williams Canyon as Mississippian and as a member of the Leadville Limestone. The Williams Canyon Member is about 44 feet thick along Gove Creek (Sec. 2; T. 10S, R. 69 W.) as measured by Hill (1983) and is considered to be a shallow marine deposit (Myrow and others, 1999).

Om **Manitou Formation (Lower Ordovician) —** The Manitou Formation consists of resistant, fine-grained limestone and dolomitic limestone. The formation is easily recognized by pink to pinkish-gray carbonates that weather to a fine, reddish-colored soil. The formation in the map area is composed of two slightly different and informal members. The lower member rests unconformably on the Sawatch Formation, described as the Mid-Rossodus unconformity, based on extensive biostratigraphic investigations by Myrow and others (2003). The lower member is a pink to light-red to maroon, fine-grained limestone and dolomitic limestone. Beds average 4 to 6 inches in thickness with occasional 1 to 2 foot beds. The upper member is composed of thicker beds (1-3 feet) of more coarsely crystalline light-pink to light-gray limestone and dolomitic limestone, with thin, resistant, gray chert layers occurring near the top. The combined thickness of the two members is 130 feet where measured in Gove Creek Canyon (NE ¼, sec. 2, T. 10 S., R. 68 W.) by Malek-Aslani (1950). The Manitou Formation is locally fossiliferous, represented primarily by Lower Ordovician conondonts. However, incomplete and poorly preserved parts of trilobites were described by Berg and Ross (1959). Descriptions of wave-rippled grainstones, thin-bedded and bioturbated micrites, and fossil assemblages of trilobites and gastropods described by Myrow (1998) are indicative of a shallow marine environment of deposition for the Manitou Formation.

Ꞓs **Sawatch Sandstone (Cambrian)** — The unit is a friable, fine- to coarse-grained sandstone, with subrounded to well-rounded quartz grains. It is predominantly gray or tan in color, but may also be pink and red. The unit is planar bedded, with isolated intervals of 2- to 6-inch thick trough cross beds. At the base of the Sawatch, angular grains of potassium feldspar comprise up to 5% of the clasts. While only minor amounts of glauconite occur at the top of the Bear Creek section, Malek-Aslani (1950) observed glauconitic-rich Sawatch Sandstone three miles to the east-southeast of Bear Creek in Gove Creek Canyon. The unit shows an overall fining upward trend, with coarse and very coarse sands at the base, and fine to medium grained sands at the top of the section. The Sawatch Sandstone weathers to gray and pale red, and forms a series of slabby cliffs on the north wall of Bear Creek Canyon. A nonconformity separates the sandstone from the Pikes Peak Granite below. The formation is approximately 60 feet thick and likely formed in a transgressive tidal environment (Myrow and others, 1999).

NEOPROTEROZOIC IGNEOUS ROCKS OF THE PIKES PEAK BATHOLITH

Neoproterozoic granitic rocks of the Pikes Peak batholith are the oldest rocks exposed in the Larkspur quadrangle. The Pikes Peak batholith is exposed over an area of 1,200 square miles 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.

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 minerals. Foord and Martin (1979) and Muntyan and Muntyan (1985), among others, describe the mineralogy of the pegmatites in the Pikes Peak batholith.

Ypp **Pikes Peak Granite (Neoproterozoic) —** Resistant, red, pink, and locally pinkish-gray and greenish-gray, coarse-grained granite intrusions. The Pikes Peak Granite is composed chiefly of quartz, feldspar, and hornblende with minor amounts of biotite, however the composition may vary locally. Feldpsar crystals can be up to 1-inch in length, are commonly anhedral, and stained red. Orthoclase and microcline, which occur as isolated crystals or intergrowths, are the most abundant feldspars. Quartz occurs as milky white, individual irregular shaped grains or as small masses of several crystals. Biotite is visible as grayish black, book-like sheets not exceeding 3-inches in longest dimension. These may weather out, leaving small cavities and give the granite a pitted appearance. The rock is part of the Pikes Peak batholith, a huge anorogenic plutonic mass that is accompanied by several late-stage alkalic phases from several intrusive centers (Barker and others, 1975; Wobus, 1976; Smith and others, 1999a). Some of these centers are bounded by all or parts of large oval- to circular-shaped ring faults and dikes (Wobus, 1976; Scott and others, 1978), perhaps the deep expression of calderas that have long been eroded away. The Pikes Peak Granite has sharp intrusive contacts, as opposed to older intrusive masses. The Pikes Peak Granite commonly weathers to grus, especially on north-facing slopes; deeper weathering, through processes described by Blair (1976), can result in a residuum cover as much as 150 feet thick (Blair, 1976; Moore and others, 2002). The age of the Pikes Peak Granite is about 1.08 to 1.02 Ga (Bickford and others, 1989; Smith and others, 1999a).

STRUCTURAL GEOLOGY

The structural geology of the Larkspur quadrangle is represented by flat lying or very gently dipping Denver Formation and Dawson Arkose strata in the eastern half of the quadrangle, locally fractured and faulted Pikes Peak Granite in the southwestern part of the quadrangle, and faulted and moderately northeast-dipping Paleozoic and Mesozoic strata in the northwestern part of the quadrangle. A few strike and dip symbols are shown on the map where the Denver and Dawson formations crop out in the eastern part of the quadrangle. Measurement of strike and dip in the Denver and Dawson formations is difficult and questionable because of the coarse-grained, lenticular and cross-bedded character of most of the beds and because of poor exposures. Bedding surfaces and cross-bed orientation from these beds were inclined at deposition and are unlikely to be representative of the strike and dip of the whole unit. Strike and dip measurements shown on the map were made on thin-bedded, fine-grained strata that were more likely deposited in a horizontal orientation. The Denver Formation strata dip more steeply towards the east in the northern part of the map area. These inclined beds appear to be dragged upwards in response to down-to-the-east motion along a fault that strikes north-south through the northern part of the map area. This fault is shown on the adjacent Dawson Butte quadrangle map where it is referred to as the West Plum Creek splay (Morgan and others, 2004). The fault projects into the Larkspur geologic map area in sec. 24, T. 9 S., R. 68 W. and appears to join the Rampart Range fault near Metz Canyon in sec. 12, T. 10 S., R. 68 W. The Rampart Range fault is a major structural feature in the Larkspur quadrangle where it separates the Precambrian Pikes Peak Granite from the Denver Formation throughout the central and south-central parts of the quadrangle. This fault is poorly exposed, but has been documented by mapping to the south to be a high-angle reverse fault (Morgan and others, 2003). The Perry Park-Jarre Canyon fault is a northwest-southeast striking fault in the extreme northwest part of the quadrangle. The fault is mostly concealed by Quaternary deposits except for a key area where it visibly places Pennsylvanian-Permian Fountain Formation rocks against the Pikes Peak Granite. Numerous high-angle faults exist in the Proterozoic rocks of the Rampart Range and were mapped primarily on the basis of an increase in fracture density, slickensides, lineaments on air photos, and DEM photography.

Rampart Range Fault

The Rampart Range fault is the largest structural feature in the Larkspur quadrangle. This regional-scale, up-to-the-west, high-angle reverse fault transects the central two-thirds of the quadrangle from south to north. The fault trace can be followed for a distance of greater than 25 miles from Metz Canyon, immediately northwest of the Larkspur quadrangle center (sec. 12, T. 10 S., R. 68 W), south to Colorado Springs. The fault serves as the southwestern boundary of the Denver Basin separating the Neoproterozoic Pikes Peak batholith on the west from younger sedimentary rocks to the east. In the Larkspur quadrangle, the footwall sedimentary rocks consist of the Denver Formation. This offset requires a displacement on the Rampart Range fault in the southern two-thirds of the quadrangle in excess of 11,000 feet. Near Metz Canyon, the Rampart Range fault and bifurcations of the West Plum Creek fault to the north are all obscured by Quaternary deposits. Immediately northwest of these Quaternary deposits (W ½ sec. 1, T. 10 S., R. 68 W.) the Pikes Peak Granite and the Cambrian Sawatch Formation are juxtaposed; however, steep dips in the Sawatch and Manitou Formations suggest faulting may be present between the granite and the Sawatch. The displacement on this fault (presumed to be the northwestern extension of the Rampart Range fault) can be no greater than 85 feet, the thickness of the Sawatch Formation. Farther to the northwest, at Gove Creek and Starr Canyons, the Sawatch Formation is in nonconformable contact with the granite, which means this small extension fault has either died out or has changed strike into the Fountain Formation where its presence is difficult to ascertain. The latter interpretation is what is depicted on Plate 1. These relations strongly suggest that the 11,000 feet of displacement on the Rampart Range fault is being transferred to the bifurcations of the West Plum Creek fault near Metz Canyon. The bifurcations appear to join and form the West Plum Creek fault in the SE ¼ of sec. 25 of T. 9 S., R. 68 W.

The Rampart Range fault is very poorly exposed in the quadrangle, usually being covered with colluvium (Qc) or other surficial deposits. In the southwest corner of sec. 20, T. 10 S., R. 67 W. the fault trace is constrained within about 200 ft between sheared Pikes Peak Granite and surprisingly little disturbed, nearly flat-lying, beds of Dawson Arkose. The approximate trace of the fault can be followed northwest of Palmer Lake between the same two units, but the fault is not exposed. Sheared blocks of Denver or Dawson formation arkose, with abundant deformation bands, were found in the small valley where the Rampart Range fault crosses the south border of the quadrangle. The best exposure of the fault occurs on the south side of the gravel pit shown as an area of human-made artificial fill (af) in the NW 1/4 sec. 32, T. 10 S., R. 67 W. Here, sheared red sandstone of the Denver Formation can be seen in juxtaposition with shattered and sheared Pikes Peak Granite. This exposure was found to be somewhat slumped and sloughed-over in the summer of 2004, but it could be cleaned off and re-exposed with moderate effort and permission from the owners.

Structural and stratigraphic relationships, along with paleontological constraints in the syntectonic Denver Formation and Dawson Arkose, suggest that the dominant movement on the Rampart Range fault occurred during the Laramide Orogeny from Late Cretaceous to middle Eocene time (Tweto, 1975 and 1980; Raynolds, 1997). No observed field evidence in the Larkspur quadrangle is suggestive of Quaternary movement on the Rampart Range fault; however, Quaternary movement has been documented on the fault further to the south in the Cascade quadrangle (Scott, 1970; Dickson, 1986). A small earthquake occurred in the Perry Park area in December of 1994 (see Geologic Hazards section in this report) which indicates some tectonic activity exists in the vicinity of the fault to the present day.

West Plum Creek Fault

The West Plum Creek fault was named and described from field mapping in the Dawson Butte quadrangle which adjoins this quadrangle to the north (Morgan and others, 2004). Although the fault is concealed, its north-south strike through the north-central part of the Larkspur quadrangle is apparent from the abrupt terminations of the southeast trending hogbacks of the resistant Dakota, Lykins, Lyons, and Fountain Formations in the western, upthrown block. The eastern, downthrown block is primarily composed of the Denver Formation until the fault bifurcates near Highway 105 in the SW ¼ of sec. 30, T. 9 S., R. 67 W. This bifurcation of the fault creates the fault wedge that is primarily composed of the Pierre Shale. At the faults northernmost point in the quadrangle, a southeasterly trending ridge of Niobrara Formation is juxtaposed to the Denver Formation requiring a displacement of around 6,500 feet. As the bifurcations join the Rampart Range fault to the south near Metz Canyon, the combined displacement is estimated to be around 11,000 feet. That the West Plum Creek fault is losing throw to the north is further supported by field evidence and data from water well drill holes outlined in the Dawson Butte quadrangle report (Morgan and others, 2004).

As discussed in the previous section on the Rampart Range fault, field evidence suggests that the West Plum Creek fault and its splays are beneficiaries of a transfer of displacement from the Rampart Range fault to the south. The Rampart Range fault is recognized for its distinct topographic and geologic division of the resistant, higher elevation, Precambrian rocks to the west from younger sedimentary strata to the east along its regional transect. The West Plum Creek fault shows little or no topographic expression and juxtaposes Paleozoic and Mesozoic rocks in the western block adjacent to Tertiary rocks in the eastern block. Therefore, the two faults are treated as separate geologic features. The increase in dips of the Denver Formation in close proximity to the West Plum Creek fault in both the Larkspur and Dawson Butte quadrangles supports reverse fault movement through the early Tertiary, suggestive of a Laramide age.

Perry Park Fault

The Perry Park fault is a north-northwest to south-southeast striking fault that is primarily concealed by Quaternary deposits in the northwestern part of the Larkspur quadrangle. Field evidence suggests that the fault initiates in the southeastern corner of section 34 of T. 9 S., R. 68 W., where westerly striking beds of lower Paleozoic strata are truncated and juxtaposed next to Proterozoic crystalline rocks. Quaternary deposits conceal the fault to the north until steeply dipping beds of the Fountain Formation are exposed near highly weathered granitic material in the south part of section 22 of T. 9S., R. 68 W. The fault zone is exposed for several tens of meters along a hiking path at this location where the Fountain Formation and Pikes Peak Granite are highly pulverized into a fine-grained powder along a weakly resistant slope. The fault is again concealed as it continues to the north into the Dawson Butte quadrangle where its trace becomes apparent from steeply dipping to vertical beds of Paleozoic and Mesozoic sedimentary strata in its footwall block (Morgan and others, 2004).

High-Angle Faults in Proterozoic Rocks

High-angle, north-south striking faults transect the Proterozoic crystalline rocks in the western half of the quadrangle as identified from the topographic map, DEM, aerial photographs, and outcrop observations where the granite shows a distinct increase in fracture density or slickenline striae. The majority of these faults are interpreted to be down-to-the east, high-angle faults which result in the progressive increase in surface elevations to the west. These faults are interpreted to be Laramide in age; however, the absence of Phanerozoic sedimentary rocks makes the determination of the relative timing of fault initiation or any later rejuvenation difficult if not impossible.

Fracture and joint data measured from the Proterozoic rocks in the Larkspur quadrangle are depicted on the map (Plate 1) and cumulatively plotted for both the Larkspur and Dakan Mountain quadrangles on a stereonet diagram (fig. 3). These data do not show a preferred strike direction; however, moderate-to-steep inclinations are dominant throughout the granite. For map display purposes the symbols for these data had to be moved slightly to allow the data to become legible. The exact UTM locations for these data can be found in Appendix A, a Microsoft Excel file on the CD ROM that accompanies the map.

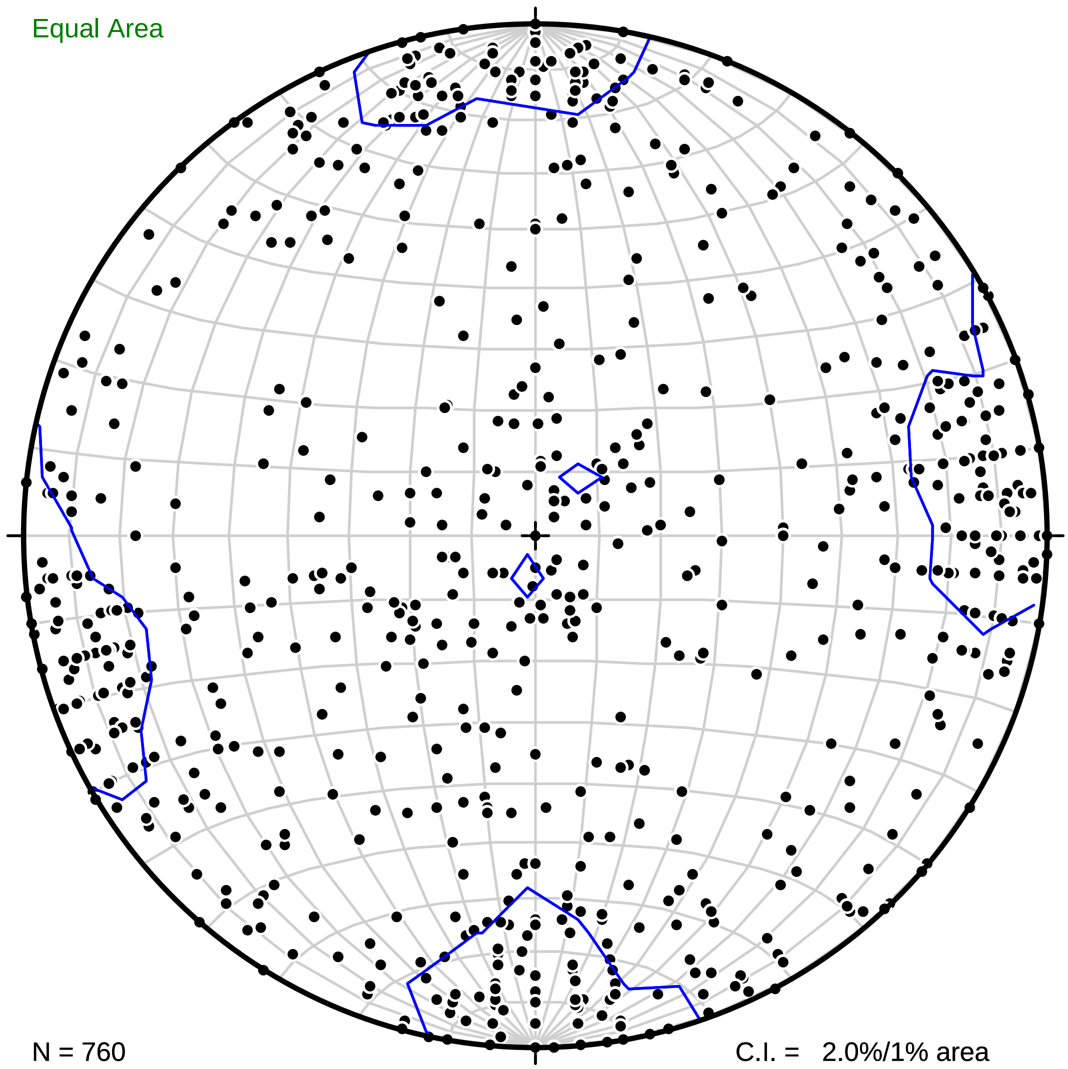


Figure 3. Stereonet diagram of poles to fracture and joint planes for 760 points in the Proterozoic crystalline rocks in the Dakan Mountain and Larkspur quadrangles. Lower hemisphere projection.

MINERAL RESOURCES

Sand and Gravel

Sand and gravel are widely available in the quadrangle from surficial deposits derived mostly from erosion of the Denver Formation and Dawson Arkose, but there is little indication that these resources are currently being exploited from the quadrangle. The gravel pit shown on the map in SW 1/4 sec. 29, T. 9 S., R. 67 W. is inactive and has been recontoured and reclaimed. The gravel pit shown on the map in sec. 32, T. 10 S., R. 67 W. was inactive during the field work in the summer of 2004. Gravel for road base material was mined from the Pikes Peak Granite in Gove Canyon in the NE ¼ of sec. 2, T. 10 S., R. 68 W. but the mine is no longer active.

Clay

Clay for brick manufacture has been mined from pits developed in the paleosol between the Denver Formation and Dawson Arkose in the Castle Rock and Parker areas. Although a similarly well developed paleosol occurs in the Palmer Lake area, and might contain acceptable clay, it has not been exploited.

Building Stone

The Wall Mountain Tuff has been extensively quarried for building stone in the Castle Rock area for over a century. The small areas of this unit on Monkey Face and Raspberry Buttes appear to be too inaccessible for consideration, however. No prospect pits or quarry sites were found. Fountain Formation sandstone was quarried on the Sandstone Ranch (S ½ , sec. 25, T. 9 S., R. 68 W.) and reportedly used on the Brown Palace Hotel in Denver.

Oil and Gas

The Colorado Oil and Gas Conservation Commission has no completion records for petroleum test wells in the Larkspur quadrangle. The nearest oil production is about 35 miles northeast of the quadrangle, north of Kiowa in Elbert County.

Ground water is the primary water source for agricultural and domestic use throughout the Larkspur quadrangle. Depending on location, ground water can be found in one, or a combination of, four hydrogeologic units: 1) Quaternary alluvial aquifers along the streams that traverse the quadrangle, 2) consolidated bedrock aquifers found in the late Cretaceous and Paleocene fluvial deposits of the Denver Basin, 3) consolidated bedrock aquifers found in the inclined Paleozoic and Mesozoic sedimentary formations at the edge of the Denver Basin, and 4) fractured crystalline rock aquifer within the Precambrian rocks of the Rocky Mountain foothills. The following sections describe each of these hydrogeologic units and provide general hydrogeologic characteristics gathered from available literature. The scope of this discussion is limited to providing a general 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

Quaternary alluvial deposits associated with West and East Plum Creeks, and their tributaries, form a major aquifer system in the Larkspur quadrangle. Flowing essentially south to north with tributaries entering from the southwest or southeast, the major streams follow well-defined valleys underlain with alluvial sand and gravel deposits derived from the foothills of the Rocky Mountains, as well as the locally exposed sedimentary rocks. The aerial extent of the alluvium is limited to relatively narrow bands along each creek, depicted on the geologic map as Qa, that generally increase in width downstream to the north. For example, there is essentially no alluvium beneath West Plum Creek where it flows through the Precambrian granite in the mountains to the west; however, at the north end of the map, the width of the alluvium where West Plum Creek meets Gove Creek is up to 1,000 feet.

The alluvium is in direct hydraulic connection with the streams and forms an unconfined aquifer where saturated with ground water. 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 imply the presence of an aquifer at depth. On the basis of records obtained from the State of Colorado Division of Water Resources (DWR), water levels in wells completed in the alluvial aquifer generally lie between the surface and approximately 16 feet below the surface. The aerial extent of the alluvial aquifer, therefore, would be expected to be somewhat smaller than that of the alluvium.

The well permit files maintained by the DWR provide limited thickness data for the alluvium. Accurate geologic logs for wells in the alluvium are rare; however, reported well depths may provide an estimation of depth. Caution should be exercised using reported well depths since it is never clear where drilling was terminated relative to the basal contact. It can only be assumed that the wells were installed to take advantage of the most favorable geologic materials for water production, which we infer to be the entire saturated alluvial sequence. On the basis of well records and topographic expression of the alluvial valleys, the thickness of the alluvium approaches 80 feet near the center of the alluvial valleys at the downstream (northern) end. Northwards, into the Dawson Butte quadrangle, the thickness of alluvium approaches 100 feet, due to the increased depth to bedrock to the north.

When provided in the permit files, the alluvium has simply been described as sand and gravel with “rocks”. In the nearby Kassler quadrangle, Scott (1963a) suggested the alluvial fill beneath the current stream channels was comprised of a thin mantle of Post-Piney Creek Alluvium (Qa_1, this map) above Pre-Wisconsin Slocum Alluvium (not mapped at the surface, this map).

The coarse-grained nature of the unconsolidated alluvium allows high well yields, with rates over 200 gallons per minute (gpm), particularly along West Plum Creek (according to DWR well records). This is substantially less than the well yields observed farther downstream to the north, where well yields of over 500 gpm are present in the DWR well records. This is likely due to a decrease in transmissivity caused by a decrease in the saturated thickness closer to the mountains.

In general, the water quality in the alluvial aquifer is suitable for domestic use. Locally, the water contains elevated levels of iron, manganese, nitrate, and selenium that can exceed applicable drinking water standards (Hillier and Hutchinson, 1980).

The Denver Basin Bedrock Aquifer System

The Denver Basin bedrock aquifer system underlies much of the Denver metropolitan area and supplies ground water to domestic, commercial, municipal, industrial, and agricultural users throughout the region. Situated within the Denver structural basin, this important aquifer system is composed of a thick sequence of sediments ranging in age from the Upper Cretaceous through Eocene. The Denver Basin bedrock aquifer system forms the principal aquifer, which communities and municipalities who do not have an adequate supply of surface water rights rely upon.

The hydrogeologic conditions of the Denver Basin bedrock aquifers are summarized in the Ground-Water Atlas of Colorado (Topper and others, 2003). The Denver Basin bedrock aquifers underlie the Larkspur quadrangle east of the Perry Park fault zone and form the primary water supply away from the Quaternary alluvial aquifers.

Details of the stratigraphy of the sedimentary sequence that forms the Denver Basin aquifer system is provided elsewhere in this document. In short, the sequence consists of interbedded sandstone, conglomerate, siltstone, and shale with coal present locally throughout the sequence. Ground water is produced from the more porous and permeable sandstone and siltstone layers of the sequence.

By statute, for the purposes of managing water use, the Denver Basin bedrock aquifer system has been subdivided into the Dawson, Denver, Arapahoe, and Laramie-Fox Hills aquifers. Water rights allocations and well permits are granted based on these designations.

Administrative separation of the Denver Basin bedrock aquifers is based on correlation of laterally extensive, shale-dominant, confining layers identified on borehole geophysical logs (primarily gamma-ray and resistivity logs) by the USGS and the DWR. The DWR has prepared a series of structural contour maps showing the elevation of the top and bottom 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, 1985) and were produced as part of Colorado Senate Bill 5 (SB-5). The SB-5 maps are used in well design and for initially determining well depths based on location. Actual well depths and well screen intervals can be modified by presenting well specific geophysical logs that support a modification of the elevation of the confining layers.

The Perry Park fault zone, which crosses the northwest corner of the Larkspur quadrangle, forms the western edge of the Denver Basin, and hence, the Denver Basin bedrock aquifers are present east of this structural feature. Surface mapping indicates that the transition from the Perry Park fault zone into the Denver Basin is rather abrupt, with beds dipping steeply near the fault and becoming more gentle a short distance away from the fault. Denver Basin formations underlying the Dawson and Denver aquifers do not outcrop at the fault zone, indicating that the underlying formations terminate at the fault contact below ground surface.

As shown in the cross-sections, the depths of the aquifers increase to the east away from the Perry Park fault in the direction of the center of the Denver Basin. Because of this regional dip, the depth of the base of the Dawson aquifer in the northeast corner of the quadrangle is estimated to be up to 950 feet below the surface, depending on surface elevation. Similarly, the depth to the base of each of the other Denver Basin bedrock aquifers in the northeast corner of the quadrangle is approximately 1,650 feet for the Denver aquifer, 2,300 feet for the Arapahoe aquifer, and 3,000 feet for the Laramie Fox Hills aquifer. By comparison, data from a borehole approximately 3,500 feet east of the fault zone and 2 miles south of the northern extent of the Larkspur quadrangle, indicate the depth to the base of the Dawson aquifer at approximately 340 feet below ground surface, while the depth to the base of the Denver aquifer is 950 feet, and the depth of the base of the Arapahoe aquifer is approximately 1,380 feet.

Water level data for the Denver Basin aquifers can be obtained from the DWR well permit files. Well completion reports and pump installation reports for wells 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 can be expected to vary considerably, depending on location and elevation, and values listed in the DWR permit base range between 35 and

824 feet below the surface in the Larkspur quadrangle.

The DWR also 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. This information can be found on the Colorado Division of Water Resources website at http://water.state.co.us/pubs/rule_reg/denverbasin. Data from wells in the Larkspur and Castle Rock area indicate water level declines averaging approximately 7 feet over a 6-year period, from 2000 through 2006, for the Dawson aquifer. Denver aquifer wells in the Larkspur and Castle Rock area average approximately 21 feet of water level decline over the same six year period. Wells in the Arapahoe aquifer in the Larkspur and Castle Rock area experienced a more significant water level decline of approximately 18 feet per year or 108 feet over the six year period. Water levels in two Laramie-Fox Hills aquifer wells declined an average of 12 feet per year for the six year period. These declines reflect heavy reliance on the Denver Basin aquifer system to meet increasing water demands.

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", meaning a well pumping at a continuous rate for 100 years will not deplete the surface stream system more than 0.1 percent, and therefore, it is not directly part of the overlying system of surface and alluvial water rights. The SB-5 maps delineate the aquifer saturated thickness and locations of nontributary and not-nontributary water. 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, 1985). More importantly, because of the poor connection with surface water and the small exposed surface area on the western edge of the basin, recharge is very limited and the ground-water resource should be considered non-renewable.

Concerns have been raised over the decline in water levels in some wells in Douglas County and that these declines may render these wells unusable in the near future, as a result of Denver Basin aquifer dewatering. The rate of water level decline that has been observed in some wells will likely decrease as the aquifers either go from a confined to an unconfined condition, or the pumping rates in intensively pumped areas are reduced as part of an overall aquifer management plan. Under confined conditions, water levels decrease at a quicker rate than unconfined conditions, as ground water is released due to a reduction in confining pressure. Once the aquifer becomes unconfined, water is released from storage, and the water level rate of decline will decrease.

Over-pumping in localized areas can have a significant effect on water levels and may cause large water level declines in isolated areas. As an example, the Town of Castle Rock Well 7C, a Denver aquifer well, had a measured water level approximately 58 feet below the top of the aquifer in 1998. The Town of Castle Rock Well 10, a Denver aquifer well, had a measured water level approximately 329 feet below the top of the aquifer in 2003. These two wells are located in an area of more intense ground water demands, where the Town of Castle Rock is pumping the aquifers for their water supply. By way of comparison, a Denver aquifer well located approximately 2 miles to the northeast, in an area where the water demands are less, had a measured water level approximately 263 feet above the top of the aquifer in 2006. Additionally, a well located six miles south of Castle Rock had a measured water level approximately 350 feet above the top of the Denver aquifer in 2006. This significant difference in water levels may be the result of heavy pumping in urban areas, or it could be due, at least partially, to a recent effort by some municipalities to better manage their pumping schedules and their peak demand pumping. There has been a recent effort by municipalities to better manage their ground water pumping by relying on their surface water supplies to reduce the stress on the aquifers during times of peak demand.

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 and 1981b, and Robson and others, 1981a and 1981b). Hillier and Hutchinson (1980) also presented limited data on near surface water quality of the Dawson aquifer. Otherwise, there is little published water quality data from locations within the Larkspur quadrangle. 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 have also been reported in water from each of the aquifers.

Older Sedimentary Bedrock Aquifers

Outside of the Denver Basin, ground water can be found in several of the older sedimentary formations that rise to the surface in the northwest region of the Larkspur quadrangle within the Perry Park fault zone. The sedimentary formations that could potentially yield water in this area consist of Cambrian through Upper Cretaceous clastic rocks and lesser carbonate rocks that are described in detail elsewhere in this report. Robson and Banta (1987) provide a description of the principal aquifers found in these older formations for the entire eastern part of Colorado wherein the aquifers are subdivided as follows:

- Fort Hayes-Codell aquifer: consists of the Upper Cretaceous Fort Hayes Limestone Member of the Niobrara Formation and the Codell Sandstone Member of the Carlile Shale, both below the base of the Pierre Shale. All of these units are present within the mapped area.
- Dakota-Cheyenne aquifer: consisting of water yielding clastic sedimentary rocks in the Lower Cretaceous Dakota Sandstone and underlying Cheyenne Sandstone Member of the Purgatoire Formation. The Dakota Sandstone and the Purgatoire Formation have been mapped in the northwest quarter of the Larkspur quadrangle.
- Entrada-Dockum aquifer: consisting of relatively coarse-grained sedimentary rocks of the Triassic Dockum Group, Triassic Jelm Formation, and the Jurassic Entrada Sandstone, and equivalent rocks. Our mapping has not identified stratigraphic equivalents of this aquifer in the Larkspur quadrangle.

- Lyons aquifer: consists of the Permian Lyons Sandstone, mapped in the northwest quarter of the Larkspur quadrangle.
- Fountain aquifer: consists of varying amounts of reddish-brown to orange to light brown, medium to coarse-grained sandstone and conglomerate interbedded with thin layers of brown shale. The Fountain Formation is present in the northwest quarter of the Larkspur quadrangle.

Unless otherwise noted, any of these aquifers could potentially provide ground water in the northwest corner of the Larkspur quadrangle. Because of the steep dip of some of these formations in the northwest region of the Larkspur quadrangle, the depths to water bearing intervals will vary depending on location. The DWR well permit records do not indicate that, within the Larkspur quadrangle, ground water is currently being withdrawn from most of the older sedimentary bedrock aquifers. The permit files have generic aquifer classifications for wells (e.g. all unnamed) so aquifer identification is not readily apparent. Well information was obtained by Martin and Wood Water Consultants, Inc., on wells completed in the Fountain and Manitou Formations in the northwest corner of the Larkspur quadrangle. The Fountain Formation can be up to 4,400 feet thick, and wells in the Fountain Formation vary from 40 feet to 800 feet deep in the northwest corner of the Larkspur quadrangle. Although there is likely some primary porosity present in the formation's sandstone and conglomerate beds, open fractures probably enhance the formation production. Well yields vary from less than one gpm to an estimated 200 gpm. The 200 gpm well is located near the West Plum Creek fault, along West Plum Creek, and was flowing under artesian conditions. The high well yield is likely driven by fracture flow, as the Fountain Formation is not known to produce such high yields from primary porosity and hydraulic conductivity. Typical well yields from the Fountain Formation range from less than one gpm to approximately 30 gpm.

One well appears to be located in the Manitou Formation near the West Plum Creek fault. The well yield was approximately 10 gpm and was flowing under artesian conditions. The Manitou Formation in the Larkspur quadrangle is of limited extent and thickness, which may limit the sustainability of the well yield.

Water quality in the older sedimentary bedrock aquifers is highly variable depending on location. Furthermore, there is little data available for this region. Although the water quality of the Dakota-Cheyenne aquifer within the Denver Basin is relatively poor (Topper and others, 2003) the ground water from this aquifer is a primary supply for the Perry Park subdivision and meets drinking water standards. The water quality in the aquifers outcropping along the northwest region of the Larkspur quadrangle is likely influenced by recharge from surface water.

Fractured Crystalline Rock Aquifer

Proterozoic igneous rocks outcrop in the west and southwest parts of the Larkspur quadrangle. Although the DWR well permit records do not show any wells in the Proterozoic igneous rocks, this aquifer is described briefly herein because it forms the primary source of ground water for populated regions of the foothills west and southwest of this area. It is also a potential source of ground water in a larger portion of the southwest corner of the Larkspur quadrangle.

Water in these crystalline rocks is produced from fractures and fault zones and well yields generally are low, although yields can potentially be relatively high if they are in hydraulic communication with a highly conductive fracture network. However, the aquifer is very often the only source of water throughout the foothills and elsewhere within the Central Rocky Mountain region. Recharge is typically from infiltration of precipitation and snowmelt and there is a delicate balance between aquifer recharge and consumption (Topper and others, 2003). Wells into these types of rocks typically can provide sufficient water for individual in-house uses, and with water quality often sufficient to meet primary and secondary drinking water standards.

GEOLOGIC HAZARDS

Several geologic processes may affect planning and ultimate development within those portions of the Larkspur quadrangle likely to be developed. In some of the steep slope areas, particularly below the steep slopes of the Dawson Arkose, the potential for debris flows and rock falls presents significant threats to developed structures. Rock stability along the upper edges of cliffs and outcrops of the same units may be tentative as large blocks of well-lithified bedrock begin to creep away as they are undermined by erosion of softer underlying strata. Slope instability and swelling soils associated with the more clay-rich portions of the Denver Formation are potential problems where this unit is exposed. Over most of the quadrangle, flooding probably represents the greatest geological threat, however. Most of the mapped part of the quadrangle contains broad open slopes with thin- to moderate-density grassland cover that offer little impediment to runoff. This area is subjected to occasional short but intense periods of torrential rain associated with summer thunderstorms. Flooding following these storms can be dramatic and dangerous.

The Rampart Range fault, which separates the Pikes Peak Granite from the Denver Formation and Dawson Arkose in the quadrangle, is one of the major structural features of the region. The Rampart Range fault is considered to be potentially active by the Colorado Geological Survey. Evidence for movement during the last two million years (Quaternary) exists for some Front Range faults including the Rampart Range fault. Earthquakes have occurred along this fault in recent times and have been felt in the Castle Rock area (December 23 and 25, 1994; December 31, 1994) and other parts of the Front Range. Other earthquakes that appear to originate from movement along this fault, or the Ute Pass fault, have been felt in Colorado Springs, Manitou Springs, Victor, and Cripple Creek (Matt Morgan, written commun., 2003). This area, like most of central Colorado, is subject to a degree of seismic risk. The Colorado Geological Survey considers this area of Colorado to be in Seismic Risk Zone 2 (Kirkham and Rogers, 1981).

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Appendix A: OFR 08-17, Larkspur Fracture Data

UTM_X_NAD83	UTM_Y_NAD83	Strike	Dip	Type	Notes
500743	4335993	170	70	Fracture	Ypp
500743	4335993	95	85	Fracture	Ypp
500406	4335818	190	80	Fracture	Ypp
500406	4335818	255	68	Fracture	Ypp
500489	4335495	180	72	Fracture	Ypp
500489	4335495	97	82	Fracture	Ypp
500960	4335430	180	80	Fracture	Ypp
501050	4335101	170	63	Fracture	Ypp
501050	4335101	280	82	Fracture	Ypp
501506	4335150	170	64	Fracture	Ypp
501506	4335150	277	80	Fracture	Ypp
501747	4335143	330	80	Fracture	Ypp
501747	4335143	260	90	Fracture	Ypp
501811	4335067	145	85	Fracture	Ypp
501811	4335067	245	88	Fracture	Ypp
502134	4335025	180	79	Fracture	Ypp
502134	4335025	250	85	Fracture	Ypp
502130	4335193	320	81	Fracture	Ypp
502130	4335193	245	62	Fracture	Ypp
502103	4335472	330	77	Fracture	Ypp
502103	4335472	75	80	Fracture	Ypp
501636	4335462	340	70	Fracture	Ypp
501682	4335853	165	72	Fracture	Ypp
501682	4335853	355	76	Fracture	Ypp
501682	4335853	80	76	Fracture	Ypp
501694	4336188	65	68	Fracture	Ypp
501694	4336188	340	75	Fracture	Ypp
501873	4336792	90	82	Fracture	Ypp
501873	4336792	345	85	Fracture	Ypp
500886	4344109	165	53	Fracture	Ypp
500886	4344109	275	70	Fracture	Ypp
500716	4336899	132	81	Fracture	Ypp
500716	4336899	231	68	Fracture	Ypp
500344	4337061	108	83	Fracture	Ypp
500344	4337061	240	84	Fracture	Ypp
500344	4337061	170	75	Fracture	Ypp
500081	4337292	336	79	Fracture	Ypp
500081	4337292	184	58	Fracture	Ypp
500081	4337292	245	62	Fracture	Ypp
500081	4337292	281	43	Fracture	Ypp
500279	4337735	293	30	Fracture	Ypp
500279	4337735	3	80	Fracture	Ypp
500279	4337735	90	75	Fracture	Ypp
500341	4338024	242	90	Fracture	Ypp
500341	4338024	326	64	Fracture	Ypp
500341	4338024	152	90	Fracture	Ypp

500341	4338024	141	14	Fracture	Ypp
500863	4338275	21	84	Fracture	Ypp
500863	4338275	95	52	Fracture	Ypp
500863	4338275	5	74	Fracture	Ypp
501097	4338802	72	75	Fracture	Ypp
501097	4338802	263	63	Fracture	Ypp
501097	4338802	174	84	Fracture	Ypp
501097	4338802	48	66	Fracture	Ypp
501221	4338133	350	75	Fracture	Ypp
501221	4338133	92	71	Fracture	Ypp
501800	4337872	87	76	Fracture	Ypp
501800	4337872	335	78	Fracture	Ypp
501800	4337872	135	90	Fracture	Ypp
502012	4337609	30	43	Fracture	Ypp
502012	4337609	153	64	Fracture	Ypp
502012	4337609	282	57	Fracture	Ypp
501781	4337279	350	71	Fracture	Ypp
501781	4337279	47	76	Fracture	Ypp
501661	4340814	324	16	Fracture	Ypp
501661	4340814	185	70	Fracture	Ypp
501661	4340814	173	68	Fracture	Ypp
501661	4340814	262	90	Fracture	Ypp
503392	4339496	132	53	Fracture	Ypp frac and sandstone dike
503392	4339496	57	65	Fracture	Ypp frac and sandstone dike
503392	4339496	272	54	Fracture	Ypp frac and sandstone dike
503392	4339496	74	74	Fracture	Ypp frac and sandstone dike
500912	4344038	92	82	Fracture	Ypp
500912	4344038	140	75	Fracture	Ypp
500912	4344038	322	40	Fracture	Ypp
501068	4336562	195	63	Fracture	Ypp
501068	4336562	275	77	Fracture	Ypp
500978	4336163	285	88	Fracture	Ypp
500978	4336163	185	70	Fracture	Ypp
501935	4336974	148	69	Fracture	Ypp
501935	4336974	284	78	Fracture	Ypp
501234	4336949	95	74	Fracture	Ypp
501234	4336949	0	67	Fracture	Ypp
502428	4337014	185	85	Fracture	Ypp
502428	4337014	65	90	Fracture	Ypp
502654	4337147	90	82	Fracture	Ypp
503149	4337173	65	78	Fracture	Ypp
503044	4337456	90	78	Fracture	Ypp
503821	4336973	345	80	Fracture	Ypp
503821	4336973	220	30	Fracture	Ypp
503821	4336973	325	28	Fracture	Ypp
503835	4336747	70	75	Fracture	Ypp
503835	4336747	175	50	Fracture	Ypp
503698	4336628	90	86	Fracture	Ypp
503698	4336628	25	48	Fracture	Ypp
503397	4336525	310	83	Fracture	Ypp

503136	4336380	75	86	Fracture	Ypp
503136	4336380	250	40	Fracture	Ypp
503136	4336380	110	66	Fracture	Ypp
503136	4336380	280	32	Fracture	Ypp
502865	4336303	35	75	Fracture	Ypp
502865	4336303	155	74	Fracture	Ypp
502208	4335892	195	75	Fracture	Ypp
502208	4335892	270	85	Fracture	Ypp
502232	4336428	260	64	Fracture	Ypp
502143	4336713	180	90	Fracture	Ypp
502143	4336713	160	62	Fracture	Ypp
501009	4343876	165	45	Fracture	Ypp
501009	4343876	250	77	Fracture	Ypp
500917	4344038	92	82	Fracture	Ypp
500917	4344038	140	75	Fracture	Ypp
500917	4344038	322	40	Fracture	Ypp
500789	4344042	59	81	Fracture	Ypp
500789	4344042	275	78	Fracture	Ypp
500789	4344042	177	18	Fracture	Ypp
500789	4344042	175	78	Fracture	Ypp
500357	4343878	168	79	Fracture	Ypp
500357	4343878	279	67	Fracture	Ypp
500357	4343878	33	77	Fracture	Ypp
504550	4333918	197	70	Fracture	Ypp
504550	4333918	270	80	Fracture	Ypp
504550	4333918	38	85	Fracture	Ypp
504550	4333918	159	73	Fracture	Ypp
504550	4333918	106	13	Fracture	Ypp
504550	4333918	170	82	Fracture	Ypp
504304	4333678	338	51	Fracture	Ypp
504304	4333678	270	75	Fracture	Ypp
503701	4333496	177	82	Fracture	Ypp
503701	4333496	280	80	Fracture	Ypp
503701	4333496	248	64	Fracture	Ypp
503135	4333633	185	68	Fracture	Ypp
503135	4333633	77	80	Fracture	Ypp
502876	4333590	145	85	Fracture	Ypp
502876	4333590	344	13	Fracture	Ypp
502876	4333590	54	90	Fracture	Ypp
502876	4333590	340	73	Fracture	Ypp
502876	4333590	302	90	Fracture	Ypp
502680	4333626	170	65	Fracture	Ypp
502680	4333626	274	82	Fracture	Ypp
502680	4333626	212	42	Fracture	Ypp
502507	4333420	172	77	Fracture	Ypp
502507	4333420	275	85	Fracture	Ypp
502119	4333058	182	78	Fracture	Ypp
502119	4333058	101	70	Fracture	Ypp
502119	4333058	345	82	Fracture	Ypp
502097	4332710	282	90	Fracture	Ypp

502097	4332710	350	72	Fracture	Ypp
502315	4332312	140	86	Fracture	Ypp
502315	4332312	300	84	Fracture	Ypp
502315	4332312	246	86	Fracture	Ypp
502315	4332312	186	13	Fracture	Ypp
502315	4332312	196	85	Fracture	Ypp
502828	4332489	260	80	Fracture	Ypp
502828	4332489	323	75	Fracture	Ypp
503165	4332769	75	74	Fracture	Ypp
503165	4332769	337	29	Fracture	Ypp
503165	4332769	143	73	Fracture	Ypp
503165	4332769	170	80	Fracture	Ypp