OPEN-FILE REPORT 05-7

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

Bill Owens, Governor,
State of Colorado

COLORADO
DEPARTMENT OF NATURAL RESOURCES

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Department of Natural Resources
Denver, Colorado
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FOREWORD

The purpose of Colorado Geological Survey Open File Report 05-7, *Geologic Map of the East half 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 this project during the summer of 2004.

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

Vince Matthews
State Geologist and Divison Director

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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.

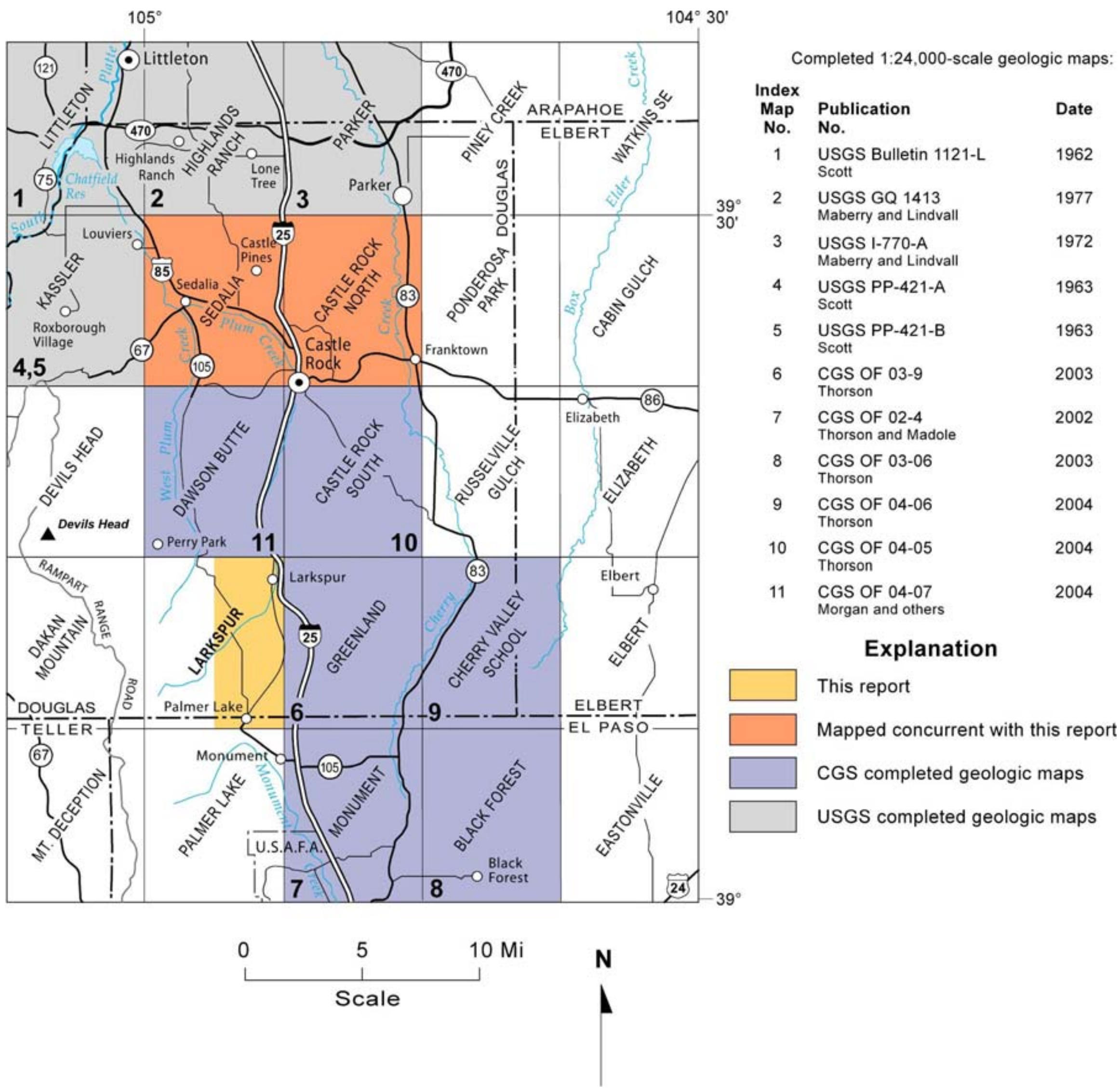

Figure 1. Index map showing the location of the Larkspur quadrangle and adjacent 1:24,000 scale mapping by the U.S. Geological Survey and Colorado Geological Survey.

In this study, only the eastern half of the quadrangle was mapped because of land access problems on critical parts of the western half. This map is based on prior published and unpublished geologic maps and reports, interpretation of aerial photography, and field mapping in 2004. The aerial photographs used are approximately 1:15,840 scale color photographs taken in 1975. 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.

ACKNOWLEDGMENTS

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 have earned my thanks: Matt Morgan and Vincent Matthews reviewed the map and text. Matt Morgan and Jason Wilson of the Colorado Geological Survey were valuable help in converting notes and field mapping on aerial photos into the geological map. Karen Morgan assembled the final cartography and booklet. 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 an asymmetrical, oval-shaped, geological structural depression called the Denver Basin (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.

Much of the exposed bedrock in the Larkspur quadrangle is the assemblage of lithologies shown on the geologic map as the upper part of the Dawson Formation (TKda). At the time of deposition of this unit 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 Dawson 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 upper Dawson 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 Formation, 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 Formation 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 Formation and also overlie a small channel filled with conglomerate of Larkspur Butte on Monkey Face buttes. 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 Formation 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 probably once covered the 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.

AGE OF FORMATIONS

Dawson Formation. The upper part of the Dawson 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). 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 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 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 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 unit TKda4 in the Larkspur quadrangle should be assigned to the Paleocene. Therefore unit TKda5 is considered to be Eocene. In the north part of the map area several paleosol occurrences were found within unit TKda4, 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 Dawson Formation in this quadrangle, as well as 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.

Conglomerate of Larkspur Butte. The conglomerate of Larkspur Butte (Thorson, 2004b) 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, 2004b), Black Forest (Thorson, 2003a), Cherry Valley School (Thorson, 2004b), and Castle Rock South (Thorson, 2004a) quadrangles. This conglomerate is clearly of Eocene age; it lies between Eocene upper Dawson Formation and late Eocene Wall Mountain Tuff. It is of probable late Eocene age because a significant part of the Eocene epoch probably passed during the deposition, alteration, and erosion of the upper Dawson. 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. Only a small channel-filing remnant of this unit, too small to be shown accurately on the geologic map, occurs in the quadrangle on the south side of Monkey Face butte.

Wall Mountain Tuff. 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). Recent radiometric dates on its eruption are about 36.7 mybp (Mcintosh and others, 1992; Mcintosh and Chapin, 1994). 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.

DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSITS

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

af **Artificial fill (latest Holocene) —** Gravel, sand, silt, clay, and rock or concrete debris emplaced for constructing highways, railroads, dams, and other human-made structrures. 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 Dawson Formation and from the Pikes Peak Granite. Most of the fragments in the channel and flood-plain (Qa) and terrace (Qt1, Qt2, Qt3) deposits are subround 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 round to subround dark-pink to light-red Pikes Peak Granite are common.

Part of the east half of the Larkspur quadrangle is mantled by older alluvial deposits of probable Pleistocene age (Qp1, Qp2, Qp3, Qp4). The relative age of these deposits has been interpreted from the slope, 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, Qp1, has surfaces which mimic the present drainage system but represent material deposited during a higher base level of the drainage than present. The position of the older alluvial deposits (Qp2, Qp3, Qp4) at higher elevation positions in the landscape than Qp1, suggests that these deposits are remnants of older drainage channels of the current drainage system.

Qa **Channel and flood-plain alluvium (late 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 Qt1. 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 soil has not developed. Unit is subject to frequent flooding. Estimated thickness is 3-7 ft.

Qt1 **Terrace alluvium one (Holocene and late 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 Qt1 in places. The unit correlates 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.

Qt2 **Terrace alluvium two (late Pleistocene) —** Very pale-brown to dark-grayish-brown, extremely poorly sorted sand and subordinate amounts of gravel. The unit correlates 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 5-15 ft higher than the larger streams. Thickness is 5-20 ft.

Qt3 **Terrace alluvium three (late 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 correspond to Louviers Alluvium of Maberry and Lindvall (1972, 1977), Scott (1962, 1963a), and Trimble and Machette (1979a). Estimated thickness is 5-30 ft.

Qsw **Sheetwash (Holocene and late 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 Dawson Formation, but a smaller amount may have been derived from the older alluvial deposits. Estimated thickness is 3-20 ft.

Qaf **Alluvial-fan deposits (Holocene and late 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. The unit is composed of material that is essentially the same as the sheetwash deposits (Qsw) and was probably largely deposited by sheet-flow processes, although it may also contain some material transported by debris-flow and mud-flow processes. The geomorphic form of these alluvial fan deposits allows them to be mapped separately. Estimated thickness is 3-20 ft.

Qafo **Old alluvial fan deposits (middle (?) Pleistocene)** — Grus-like deposits predominantly composed of quartz and feldspar sand, granules and small pebbles from disintegrated Dawson Formation arkoses, but may include occasional boulders of well cemented Dawson Formation as large as 4 feet in diameter. Unit has been mapped separately because the material appears to have been deposited by a combination of sheet-flow and debris-flow processes on moderate slopes like the alluvial fans. The unit is being eroded by streams and has lost its characteristic geomorphic shape so must be older than presently forming alluvial fans. Estimated thickness 0-50 ft.

Qp1 **Old alluvium one (late 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. The unit may have cobbly and bouldery layers with angular to subround fragments of Wall Mountain Tuff, subrounded clasts of Dawson Formation arkose, and in places abundant well rounded cobbles and small bounders of granite, gneiss, and quartzite weathered out of the Castle Rock Conglomerate. This unit appears to correlate with the Slocum Alluvium of Maberry and Lindvall (1972) but may include some material that they would have mapped as Louviers Alluvium at lower elevations. Unit correlates with the Slocum Alluvium of Trimble and

Machette (1979a) and Bryant and others (1981). Unit Qp1 is poorly exposed; estimated thickness may be a great as 60 ft.

Qp2 **Old alluvium two (Pleistocene) —** This deposit is composed of light-brown sand and fine gravel that appears to be derived from the Dawson Formation, plus cobbles and small boulders of Dawson Formation arkose, Wall Mountain Tuff, and well rounded pebbles or cobbles of Pikes Peak granite, gneiss, and quartzite. Qp2 is predominantly a gravel and small pebble unit but contains more cobbles and larger cobbles in locations close to the edge of the Pikes Peak Granite mountain front. The deposit in the SW 1/4 sec. 20, T. 10 S., R. 67 W. contains small well rounded boulders. Unit Qp2 correlates with some of the deposits mapped as Verdos Alluvium by Trimble and Machette (1979a) and Bryant and others (1981) but also includes some deposits previously mapped as Rocky Flat Alluvium by them. Unit is about 5 to 100 ft thick.

Qp3 **Old 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 Qp2, so therefore Qp3 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. Unit was mapped as Rocky Flat Alluvium by Trimble and Machette (1979a) and Bryant and others (1981). Unit is about 5 to 40 ft thick.

Qp4 **Old 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 highest elevation alluvial material in the quadrangle and apparently represents the oldest stream channels. The deposits of this unit in the southeast corner of the map area were designated 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. Therefore, this unit probably includes alluvial material that is older than Rocky Flats Alluvium, perhaps correlative with Nussbaum Alluvium, or even older. Unit is about 5 to 30 ft thick.

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. 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, (2) exposures are poor, and (3) two or more units are present but are too small to show separately at the map scale. These alluvial-filled valley heads are not exhumed or deeply incised. The unit probably includes sediment that is correlative with units Qa, Qt1, and possibly Qt2. Estimated thickness is 3-20 ft.

MASS-WASTING DEPOSITS — Earth materials that were translocated downslope under the influence of gravity. Colluvium deposits are the principal 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 are that it (1) was derived locally and transported only short distances, (2) may contain clasts of any size, (3) has no structures indicative of sedimentation or stratification by water flowing in channels, and (4) has an areal distribution that bears no relation to channelized flow of water (Madole and Streufert, 2001). Hilgard's definition allows colluvium to include a minor amount of sheetwash alluvium.

Qc **Colluvium (Holocene and upper Pleistocene) —** Unit comprises slope deposits that consist chiefly of very pale-brown to brown sand and fine gravel plus cobbles and boulders of Dawson Formation arkose, and Wall Mountain Tuff. Deposits typically are massive and very poorly sorted to extremely poorly sorted. Although primarily the product of mass wasting, the unit may include minor amounts of sheetwash. Unit is estimated to be 2-50 ft thick.

EOLIAN DEPOSITS — Wind-deposited sediment.

Qes **Eolian sand (Holocene and late 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 Qp1 alluvial unit. Thickness is estimated to be 3-15 ft.

BEDROCK DEPOSITS

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 when fresh but is occasionally medium-gray 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 Wall Mountain ash-flow was erupted from the 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 Formation. On the 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 Formation TKda6 and filled with conglomerate of Larkspur Butte, that is too small to show accurately on the geologic map.

Tlc **Conglomerate of Larkspur Butte (late? Eocene) —** 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 Formation 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 Formation 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 smalll 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.

Dawson Formation (Upper Cretaceous to Eocene) — 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 (TKda1), facies unit two (TKda2), facies unit three (TKda3), facies unit four (TKda4), and facies unit five (TKda5). A sixth facies unit has been recognized locally in the Cherry Valley School (Thorson, 2004b) and Larkspur quadrangles. 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. Only facies unit four (TKda4), facies unit five (TKda5), and facies unit six (TKda6) are present in the Larkspur quadrangle.

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.

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 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; Kelley, 2002; Farnham and Kraus, 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, 2005; 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, facies units TKda5 and TKda6 of this report appear 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 the quadrangle.

TKda6 **Facies unit six (middle to late Eocene) —** Unit TKda6 is very similar to the underlying Dawson Formation unit TKda5 in bedding style and bedding thickness. It differs in being more firmly cemented, so stands in very steep to vertical cliff faces in the two remnants of this unit on Monkey Face and Raspberry Butte, and containing a noticeably higher concentration of subround to well rounded white quartz pebbles and small cobbles. This unit may represent very late Dawson Formation material that was being eroded from the upturned edge of older Dawson Formation units along the west edge of the Denver Basin. Such an origin would account for the concentration of resistant white quartz fragments, particularly if the feldspars in the eroded older Dawson Formation arkoses and conglomerates had already begun to be diagenetically altered to clay, reducing their resistance to abrasion. Unit TKda6 is about 40 ft thick.

TKda5 **Facies unit five (early to middle? Eocene) —** The TKda5 unit is dominated by very thick-bedded to massive, cross-bedded, light-colored arkoses, pebbly arkoses, and arkosic pebble conglomerate, but alsothe 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 finner-grained parts. Facies unit five also contains a few massive structureless beds interpreted to be mudflows and common beds of greenish-gray to olive-green sandy claystone. Occasionally unit TKda5 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. TKda5 is at least 400 ft thick in the quadrangle but the top of the unit has been removed by erosion in most places. TKda5 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).

TKda5 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 facies unit five poses a possible slope-stability hazard in some areas. Facies unit five appears to be equivalent to the Dawson Arkose and/or Dawson aquifer in the Denver area (George VanSlyke, 2001, oral commun.).

TKda4 **Facies unit four (early Paleocene) —** Facies unit four 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 TKda5. 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 in the quadrangle is estimated to be greater than 300 feet.

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 four 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). This paleosol is well exposed only 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 115 (Perry Park Road) near the south edge of sec. 17, T. 10 S., R. 67 W. Other poorly exposed paleosols occur within Dawson Formation unit TKda4 near the north edge of the quadrangle. Here a note of caution must be 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.

TKda4 appears to correlate with the top of Raynolds' (2002) D1 sequence, 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 TKda4 nor the lower facies units of the Dawson Formation are exposed in the Larkspur quadrangle.

Facies unit four 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 area to excavate areas of TKda4 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 TKda4.

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

Ypp **Pikes Peak Granite (middle Proterozoic) —** Resistant red, pink, and reddish-brown coarse-grained granite intrusions. The Pikes Peak Granite is composed chiefly of gray quartz, reddish-colored feldspar, and dark hornblende with minor amounts of black biotite; however, the composition may vary locally. Grain size is quite coarse with anhedral feldspar crystalls up to 1-inch in size. The feldspar varities are orthoclase and microcline often occurring as intergrowths. The Pikes Peak Granite disintegrates on weathering to loose grains making a material called grus. The age of the Pikes Peak Granite is about 1.02 to to 1.08 billion years (Bickford and others, 1989; Smith and others, 1999).

STRUCTURAL GEOLOGY

The structural geology of most of the Larkspur quadrangle is not complex. Most of the Dawson strata are flat lying or very gently dipping. Few strike and dip symbols are shown on the map.   Measurement of strike and dip in the Dawson Formation 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 Dawson Formation strata dip more steeply towards the east in the northwestern corner of the map area.   These inclined beds appear to be dragged upwards in response to down-to-the-east motion along a concealed fault that lies just west of the northwest corner of the map area.   This fault is shown on the adjacent Dawson Butte quadrangle map (Morgan and others, 2004) and projects into the Larkspur geologic map area in sec. 31, T. 9 S., R. 67 W.   A Hembre and TerBest (1997, figure 3) cross section for the Perry Park area shows reverse motion on this fault, which they call the Perry Park Fault. For further discussion of the structure of the Perry Park area, west of the area mapped for this report, see Morgan and others (2004) and references therein.

The Rampart Range fault is a major structural feature in the Larkspur quadrangle where it separates the Precambrian Pikes Peak Granite from the Dawson Formation. Several thousands of feet of offset have occurred on this structure and it may have reverse motion like the Perry Park fault. 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 Formation unit TKda5.   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 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 Dawson Formation unit TKda4 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.

MINERAL RESOURCES

Sand and gravel are the most significant potential mineral resources in the Larkspur quadrangle.   No radioactive mineral resources are known in the quadrangle.

SAND AND GRAVEL

Sand and gravel are widely available in the quadrangle from surficial deposits derived mostly from erosion of the Dawson Formation, 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.

CLAY

Clay for brick manufacture has been mined from pits developed in the paleosol between TKda4 and TKda5 in the Castle Rock and Parker areas. Although this paleosol is well developed 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.

OIL AND GAS

The Colorado Oil and Gas 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.

WATER RESOURCES

Water resources in the Larkspur quadrangle are contained either in shallow groundwater aquifers in surficial alluvial deposits along the major stream drainages, largely the terrace deposits Qt1, Qt2, and Qt3, or in deeper groundwater aquifers of the Denver Basin (Robson, 1987, 1989; Topper and others, 2003). This basin contains four major aquifers, listed from the top down: Dawson, Denver, Arapahoe, and Laramie-Fox Hills. A comprehensive review of the geology and issues associated with ground water supply in the Larkspur quadrangle is well beyond the scope of this report. The interested reader is referred to Topper and others (2003), Raynolds and Reynolds (2004), and Morgan and others (2004, 2005) where the topic is discussed in detail.

GEOLOGIC HAZARDS

Several geologic processes may effect 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 Dawson Formation, 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 Dawson 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 Dawson Formation 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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