# Geology of Upper Cretaceous, Paleocene and Eocene Strata in the Southwestern Denver Basin, Colorado

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Cover: Photo, Vince Matthews. Pulpit Rock in Colorado Springs is comprised of cliffs of the newly-named Pulpit Rock Formation of the Denver Basin Group. The greenish-gray slope is the newly-named Pikeview Formation of the Denver Basin Group. This striking feature was originally called Windsor Castle (inset) in the 1869 Annual Report of the United States Geological and Geographical Survey of the Territories which was led by F. V. Hayden.

Layout: Larry Scott, Colorado Geological Survey, 2011

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# ABSTRACT

Between 1999 and 2008 the Colorado Geological Survey mapped and published open-file reports covering twenty preliminary 7.5 minute quadrangles in the area between Colorado Springs and Denver. Most of these quadrangles contain exposures of Upper Cretaceous through Eocene strata deposited as synorogenic sedimentary units that filled the Laramide Denver Basin. This report unifies and simplifies the stratigraphy and nomenclature of units on those preliminary maps and reports. In this report, the Upper Cretaceous to Eocene synorogenic units filling the Denver Basin are renamed as the Denver Basin Group.

In the Colorado Springs area the Denver Basin Group stratigraphic section is composed of five units, in ascending order:

1. a basal late Cretaceous unit (Kpv) composed almost exclusively of andesitic debris and introduced from the southwest. This unit, previously only designated the "lower part of the Dawson Formation", has herein been named the Pikeview Formation of the Denver Basin Group;

2. the Pulpit Rock facies unit (TKpr) composed almost exclusively of granitic debris shed eastward from the rising mountain front, herein designated as the Pulpit Rock Formation of the Denver Basin Group;

3. the Jimmy Camp facies unit (TKjc) of mixed volcanic and granitic composition introduced into the Denver Basin from the south, herein designated as the Jimmy Camp Formation of the Denver Basin Group;

4. the Black Squirrel Formation (Tbs), a finer-grained mixed composition unit that can be mapped south of the Palmer Divide, and that is probably partially equivalent to part of the Denver Formation north of the Divide and in the Denver area, and

5. the Dawson Arkose (Tda) which can be mapped continuously from the north side of Palmer Divide to the southern edge of the Denver metropolitan area.

In the Castle Rock area, the Denver Formation and the Dawson Arkose make up the entire exposed Denver Basin Group section. The Laramide synorogenic sedimentary units are overlain by the remnants of three younger Eocene units; the Larkspur Conglomerate, Wall Mountain Tuff, and Castle Rock Conglomerate. The Larkspur Conglomerate is a newly named coarse arkosic conglomerate identified by Richardson in 1915, which remained unmapped and undescribed until the mapping program compiled and summarized here.

# FOREWORD

Recognizing that the Denver Basin, freshwater aquifers were under extreme pressure, CGS began a decade-long mapping campaign in 1999 to map the aquifers where they were exposed along the flank of the mountains at 1;24,000 scale. The intent was to understand what the geological architecture of the aquifers was where we could observe them at the surface. Once that was completed CGS began applying that knowledge to understanding the aquifers where they were buried.

This report, and the accompanying 1:50,000-scale map, synthesize what was learned from the mapping of those quadrangles. Although many different mappers were involved in mapping the 20 different quadrangles, Dr. Thorson was involved in the majority of them involving the Denver Basin aquifers. This report also presents a revised nomenclature that makes it easier to understand the relationships of the strata in different parts of the Denver Basin.

This mapping project was funded jointly by the U.S. Geological Survey (USGS) and the Colorado Geological Survey (CGS). USGS funds were received under competitive STATEMAP award numbers 08HQAG0094,. STATEMAP is a component of the National Cooperative Geologic Mapping Program, which is authorized by the National Geologic Mapping Act of 1997and 2000. Matching funds were drawn from the Colorado Department of Natural Resources Severance Tax Operational Funds, which are obtained from the Severance Tax paid on the production of natural gas, oil, coal, and metals in Colorado.

Vince Matthews
State Geologist of Colorado
Director of the Colorado Geological Survey

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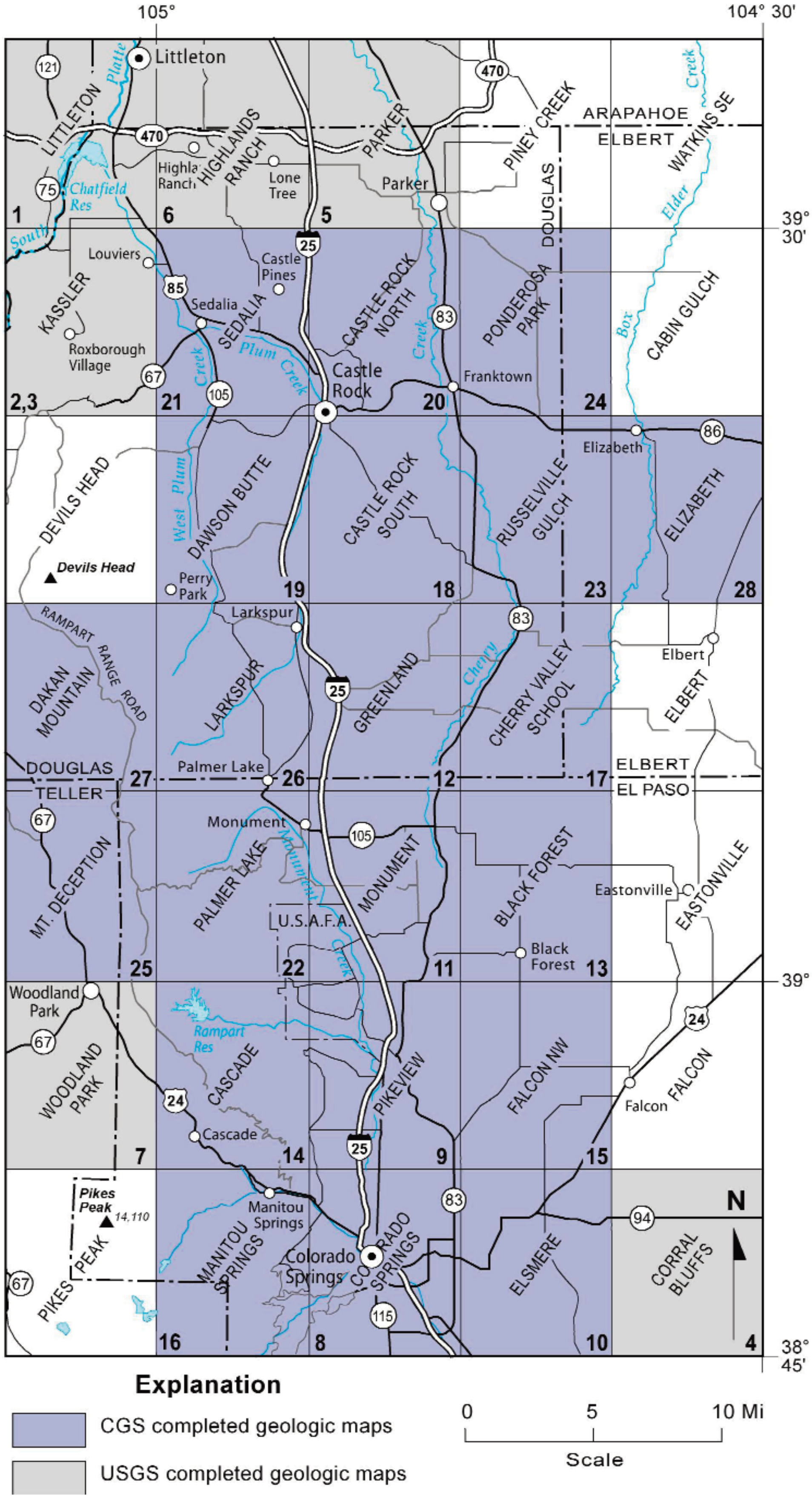
# INTRODUCTION

During the period between 1999 and 2007, the Colorado Geological Survey (CGS) conducted a geological mapping program, the Front Range project, in the area extending from Colorado Springs to the southern edge of the Denver metropolitan area in Highlands Ranch and Parker. Although part or all of this area has been mapped several times in the last century, little of that mapping has been done at a detailed scale. The major concerns driving this mapping program were development and water resources, followed by geological hazards and mineral and energy resource evaluations. This area has seen rapid expansion of suburban development encroaching southward from Denver and northward from Colorado Springs. Furthermore, the southwestern part of the Denver Basin has seen huge demands on groundwater resources to support that development. The CGS Front Range mapping project resulted in the release of twenty 24,000 scale open-file geological maps shown on **figure 1**. This report, and the 50,000-scale map that accompanies it (**Plates 1, 2 and 3**) summarize the geology of the Upper Cretaceous through Eocene strata in this developing metropolitan corridor. These strata are the foundations of this development, and much its water source.

Plates 1, 2 and 3, in pocket. Geology of Upper Cretaceous, Paleocene and Eocene strata in the southwestern Denver Basin, Colorado.

The area summarized in this report is located in the southern part of the Colorado Piedmont section of the Great Plains. The northern part is mostly located in the Cherry Creek and Plum Creek drainage basins, which are tributary to the South Platte River (**figure 2**). Minor parts of the Box Elder Creek drainage basin are included along the northeastern edge. The southern part of the area is located in the drainage basins of Monument Creek, Jimmy Camp, and Black Squirrel Creeks, tributaries of the Arkansas River. Geologic mapping in the Front Range project was undertaken by the Colorado Geological Survey (CGS) as part of the STATEMAP component of the National Cooperative Geologic Mapping Program. The open-file 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. Those maps were based on prior published and unpublished geologic maps and reports, interpretation of aerial photography, and field mapping.

Previous geological mapping in the area between Denver and Colorado Springs includes the work of Emmons and others (1896), Richardson (1915), and Finlay (1916). Scott (1962, 1963a,b) and Scott and Wobus (1973) published geological maps of the Littleton, Kassler, and Colorado Springs areas, respectively, for the US Geological Survey. Maberry and Lindvall (1972, 1977) mapped the Parker and Highlands Ranch quadrangles. Trimble and Machette (1979a, 1979b) published 1:100,000 scale regional geologic maps of the Front Range urban corridor. Bryant and others (1981) compiled a 1:250,000 scale map of the Denver 1° x 2° quadrangle. The geology of most of the area mapped at 1:24,000-scale by the Colorado Geological Survey (figure 1) has never before been mapped at this detail.




Completed 1:24,000-scale geologic maps:

| Index Map No. | Publication No. | Date |
|---|---|---|
| 1 | USGS Bulletin 1121-L<br>Scott | 1962 |
| 2 | USGS PP-421-A<br>Scott | 1963 |
| 3 | USGS PP-421-B<br>Scott | 1963 |
| 4 | USGS GQ-783<br>Soister | 1968 |
| 5 | USGS I-770-A<br>Maberry and Lindvall | 1972 |
| 6 | USGS GQ 1413<br>Maberry and Lindvall | 1977 |
| 7 | USGS MF-842<br>Wobus and Scott | 1977 |
| 8 | CGS OF 00-03<br>Carroll and Crawford | 2000 |
| 9 | CGS OF 01-03<br>Thorson and others | 2001 |
| 10 | CGS OF 02-02<br>Madole and Thorson | 2002 |
| 11 | CGS OF 02-4<br>Thorson and Madole | 2003 |
| 12 | CGS OF 03-9<br>Thorson | 2003 |
| 13 | CGS OF 03-06<br>Thorson | 2003 |
| 14 | CGS OF 03-18<br>Morgan and others | 2003 |
| 15 | CGS OF 03-8<br>Madole | 2003 |
| 16 | CGS OF 03-19<br>Keller and others | 2005 |
| 17 | CGS OF 04-06<br>Thorson | 2004 |
| 18 | CGS OF 04-05<br>Thorson | 2004 |
| 19 | CGS OF 04-07<br>Morgan and others | 2004 |
| 20 | CGS OF 05-02<br>Thorson | 2005 |
| 21 | CGS OF 05-06<br>Morgan and others | 2005 |
| 22 | CGS OF 06-06<br>Keller and others | 2006 |
| 23 | CGS OF 06-08<br>Thorson | 2006 |
| 24 | CGS OF 07-04<br>Thorson | 2007 |
| 25 | CGS OF 07-07<br>Temple and others | 2007 |
| 26 | CGS OF 08-07<br>Thorson (updated 2008) | 2008 |
| 27 | CGS OF 08-16<br>Thorson | 2008 |
| 28 | CGS OF 09-03<br>Morgan | 2009 |

**Figure 1. Locations and references for 1:24,000 scale quadrangle maps summarized in this report.**

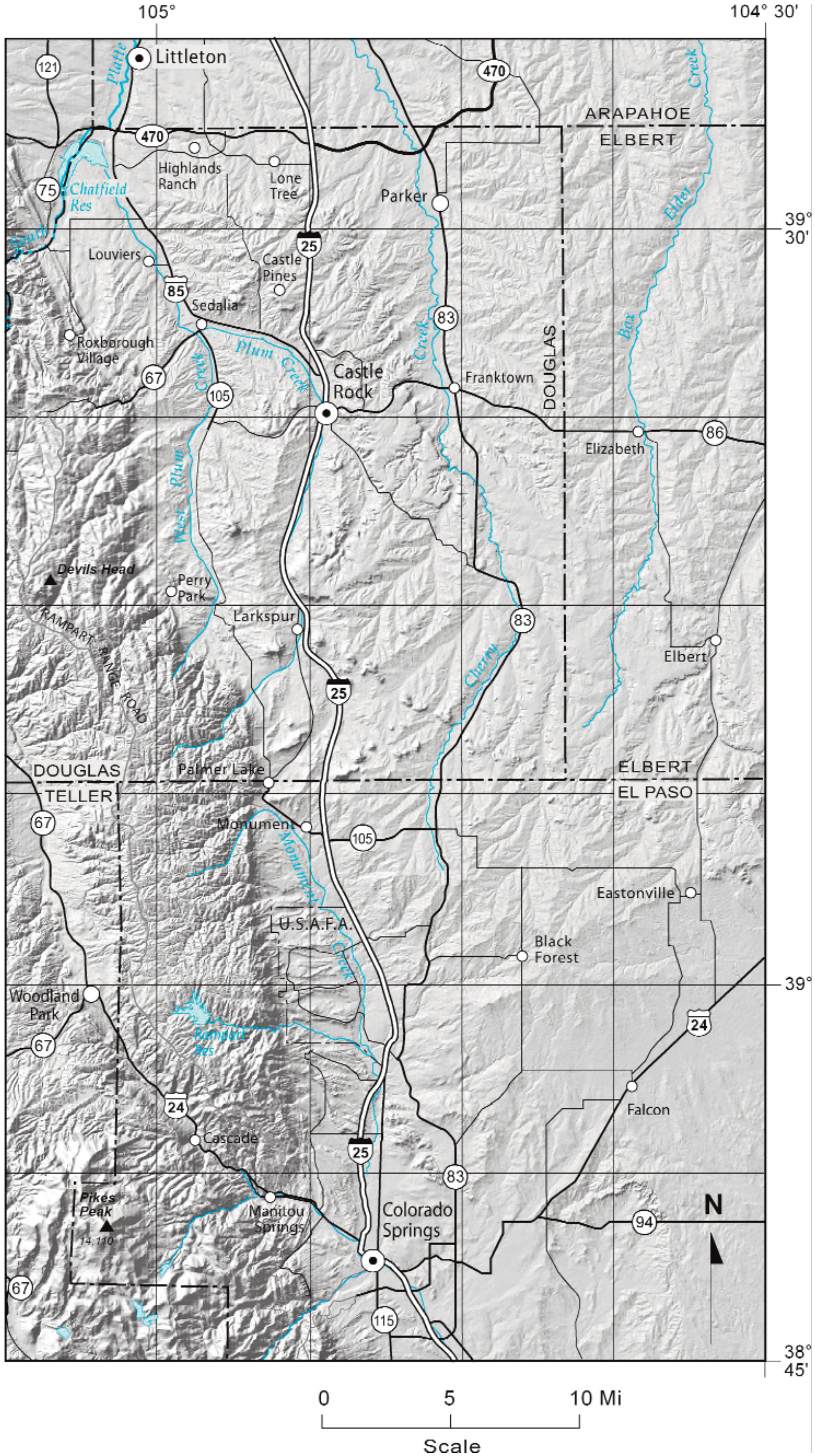



**Figure 2. Physiographic map of the Front Range Project area. The area shown is the same as shown in figure 1; 1:24,000 quadrangle boundaries are indicated.**

# ACKNOWLEDGMENTS

The mapping project described was funded jointly by the Colorado Geological Survey and the U.S. Geological Survey through the National Cooperative Geological Mapping Program. Many people deserve credit and acknowledgment. First, there are the mappers and authors who accomplished the maps shown on figure 1, listed in the references, and credited with contributions on the title page; I have tried to fairly summarize and generalize their work in this report. Any shortcomings in this matter are solely my responsibility. Thanks also to the many peer geologists, too numerous to mention, but appreciated, who reviewed all of those publications and maps, both mine and all other authors', and helped us clarify what we were trying to explain. And also, to Jane Ciener, technical editor for CGS who pointed out that we had crossed the "i's" and dotted the "t's", and used "which" when we meant "that", only didn't know it; thank you. I can sometimes now write a complete sentence.

Then, there are "Thank you's" to Peter Barkmann, Cheryl Brchan, Jim Cappa, Bob Kirkham, Vince Matthews, Matt Morgan, Dave Noe, Larry Scott, Beth Widman, and Jason Wilson at Colorado Geological Survey; you each supported the Statemap program in your own ways. Karen Morgan deserves special thanks for her great patience and persistence in compiling the 1:50,000-scale map in Plate 1 and 2. She made it all fit together

My friends at Denver Museum of Nature & Science (DMNS) and the NSF-funded Denver Basin Project; Kirk Johnson, Bob Raynolds, Beth Ellis, Michelle Reynolds, and Marieke Dechesne supported my work on the petrology and geochemistry of the volcanic pebbles in Denver Basin conglomerates, parts of which are incorporated in this report. National Science Foundation grant number EAR-0345910 supported my work as a minor contribution to the larger study of the Denver Basin by DMNS. Paula Hansley of Petrographic Consultants International, Inc. examined many ugly thin sections of badly altered volcanic pebbles for that study; my sympathies and thanks are due.

The late Douglas Nichols, working through the Denver Museum of Nature & Science, identified and dated pollen in a few of many samples I submitted for palynology, and opened up huge, as yet unresolved, questions about the later Paleocene history of the Denver Basin.

George D. Vanslyke, Colorado Division of Water Resources, provided generous access to his agency's files of water-well logs.

Special thanks go to the landowners and developers who granted permission to enter their properties.

# GEOLOGIC SETTING

The area described in this report is located in the southwestern part of the Denver Basin, an asymmetrical, oval-shaped, geological structural depression defined by Emmons and others (1896). This structural basin lies directly 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 southwestern part of the Denver Basin is an assemblage of synorogenic sedimentary lithologies deposited during the Upper Cretaceous, Paleocene, and Eocene Epochs (about 70 to 34 million years ago, **figure 3**) as the Front Range was uplifted and exposed. Braided streams delivered to the basin a mixture of gravel, sand, silt and clay derived from weathering and erosion of that uplifted area. Early in the uplift, an andesitic volcanic complex, probably located southwest of the basin, was eroded and deposited as Upper Cretaceous andesitic mudstone, sandstone and conglomerate unit in the Colorado Springs area. Near the end of the Cretaceous the andesitic volcanic rocks were completely removed from parts of the source terrane, and the Precambrian granite roots of the Front Range began to be eroded. Deposition of arkosic sandstones and comglomerates composed largely of granitic and metamorphic debris were then deposited across the basin.

In the Colorado Springs area the source of those granitic arkosic materials was mostly the Precambrian Pikes Peak Granite, located directly west of the Rampart Range mountain-front fault system. Farther to the north, along the western edge of the Denver Basin, the conglomerates and arkosic sandstones had a mixed source of granites, metamorphic rocks, and minor remaining volcanics. Stream flow was generally towards the east (Morse, 1979; Crifasi, 1992).

In the Colorado Springs area a series of new formations have been recognized and are herein named. In these units, pebble conglomerate and arkosic sand beds of the Pulpit Rock, Jimmy Camp, and Black Squirrel Formations and Dawson Arkose, 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 these units were deposited by gentler currents in areas between the braided stream channels and probably were covered with vegetation. In the Castle Rock area similar facies are present in the Denver Formation;

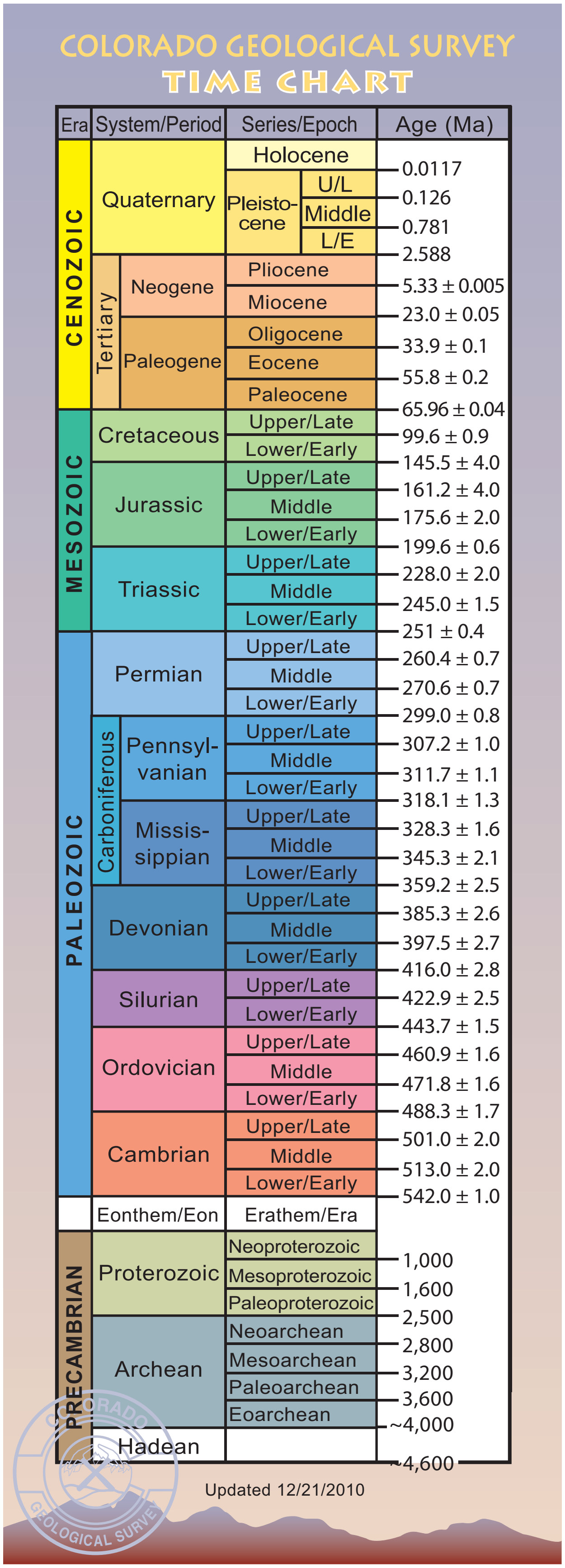



**Figure 3. Geological time chart used by CGS.**

large fluvial fan systems of relatively coarse-grained material near the mountain front break up into individual channels towards the east and become finer grained.

Following renewed uplift and the erosion of some of the upper part of the Dawson Arkose, probably during the middle of the Eocene Epoch, the Larkspur Conglomerate (conglomerate of Larkspur Butte, Thorson, 2003a) was deposited in a series of channels and broad valleys occupied by streams that drained the newly rejuvenated mountains. In the western part of the Greenland quadrangle, the Larkspur Conglomerate was deposited in narrowly confined, steep-walled stream valleys. These valleys became broader towards the east in the Castle Rock South and Cherry Valley School quadrangles (Thorson, 2004a, 2004b). The same eastward widening is apparent in the Castle Rock North (Thorson, 2005a) and Russellville Gulch quadrangles (Thorson, 2006).

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 that contained the Larkspur Conglomerate. Because of its great heat, the ash compacted into a viscous plastic that flowed for short distances before it cooled into welded tuff. Erosional remnants of the Wall Mountain Tuff overlie the Dawson Arkose or Larkspur Conglomerate in a broad east-northeast-trending zone across the central part of the area.

The Castle Rock Conglomerate was deposited near the end of the Eocene as broad sheets in northwest to southeast trending paleovalleys, which had been eroded across the upper Dawson Arkose, Larkspur Conglomerate, and Wall Mountain Tuff. Erosional remnants of the Larkspur Conglomerate and Wall Mountain Tuff stand at higher elevations above Castle Rock Conglomerate paleovalleys in many areas.

Since the deposition of the late 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 part of the southwestern Denver Basin, but has since been removed by erosion. During the Quaternary, deposits of unconsolidated sands and gravels were left in paleochannels, flood plains along stream courses, and on various upland erosion surfaces as streams eroded the landscape. Deposits younger in age than Eocene have been generalized together on Plates 1 and 2.

# PREVIOUS WORK

In the defining work on the stratigraphy of the Denver Basin by Emmons and others (1896) they described and named three formations; Arapahoe, Denver, and Monument Creek, in ascending order, as a clarification of the rather confused stratigraphy used by the Hayden Survey (1869 - 1875). Emmons believed the Arapahoe and Denver were Cretaceous in age.

Darton (1905) used the Arapahoe and Denver Formation names for the same parts of the sections as Emmons, but considered the ages of both to be Tertiary.

Richardson (1915) named the Dawson arkose after exposures on Dawson Butte, on the Dawson Butte quadrangle, about 5 miles southwest of the town of Castle Rock. He initiated the confusion of names by using "Dawson arkose" (lower case "a") for the section equivalent to Emmons' and Darton's units and considered these units to be Eocene age. He defined the Castle Rock Conglomerate at the top of a prominent butte at the edge of the town of Castle Rock area and suggested it to be Oligocene in age. Richardson used the symbol "Td" for his Dawson arkose, and drew attention to a "thin bed of andesitic sandstone in the upper part" of the Dawson that "expands northwestward and becomes the Denver Formation". He also identified a unit of rhyolitic lava and tuff at the top of the Dawson. He described a unit of reddish conglomeratic arkose "containing fragments of white arkose like the underlying beds and pebbles (and cobbles and small boulders, amplification by Thorson, 2003) of granite, quartz and quartzite" on the top of Larkspur Butte. He interpreted the uneven eroded surface between this conglomeratic unit and the underlying white Dawson arkose as an unconformity (Richardson, 1915. p.7)

Finlay (1916) used the same terminology and map symbol (Dawson arkose, Td) in the Colorado Springs area, and first identified the unit of "almost wholly fine-grained andesitic debris" at the base of the Dawson unit. Finlay mapped these andesitic beds as a separate andesitic sandstone member of the Dawson with a map symbol "Tda".

Johnson (1930), from work in the Denver quadrangle, suggested that the name Arapahoe Formation should be dropped as it and the Denver Formation graded laterally into the Dawson arkose.

Dane and Pierce (1936) suggested a division of the Dawson arkose into two sub-units, a lower unit of mixed lithologies and an upper unit of coarser arkosic lithology.

Brown (1943) found the location of the Cretaceous-Tertiary boundary in the Denver Formation on Green Mountain, west of Denver.

Scott (1962, 1963) continued the use of "Dawson arkose, but used the map symbol "TKda" as the Dawson was now recognized to span the Cretaceous-Tertiary boundary. He mapped the "andesitic sandstone tongue of the Denver formation" (lower case "f"), TKd, as an apparent member within the Dawson arkose, and chose not to use the name "Arapahoe" for the unit below the Denver formation.

Varnes and Scott (1967) formalized the arkose unit as Dawson Arkose (upper case "A") and used a new symbol, Kda, for the andesitic unit at the base of the Dawson in the Colorado Springs area, as this unit was now recognized to be wholly Late Cretaceous in age. They used the map symbol "TKd" for the Dawson above the Kda andesitic unit, in acknowledgment that their Dawson Arkose spanned the Cretaceous-Tertiary boundary.

Soister (1968) generalized the entire Upper Cretaceous and Paleocene Denver Basin section as Dawson Formation, TKdw, in the Corral Bluffs quadrangle without recognizing the andesitic lower part.

Maberry and Lindval (1972, 1977) used Dawson Arkose (with a formalized upper case "A") and considered the Denver Formation (Tde) as a tongue within that unit. They also choose, like Scott (1962, 1963), not to use the name "Arapahoe Formation" for the strata beneath the Denver Formation tongue. They used a complicated system of lithologies as subdivisions of the Dawson Arkose, but their sub-units of the Dawson can't be effectively used as stratigraphic map units on a large scale.

Scott and Wobus (1973) changed the Dawson name back to Dawson Formation, TKd, in the Colorado Springs area, and raised the andesitic "Lower part, Kda", to Formation status comparable to the Upper part, but did not give the new formation a unique name, simply referring to the unit as the "lower part of the Dawson Formation".

Soister and Tschudy, 1978, identified the Paleocene-Eocene boundary at six locations in the eastern part of the Denver Basin and found a prominent paleosol horizon closely below those localities, which could be "traced over most of the Basin". They concluded that the paleosol, since informally named the Denver Basin Paleosol, "may be tentatively considered as marking the Paleocene-Eocene boundary in the Denver Basin. In most areas where the paleosol is missing, it is believed to have been present originally but to have been removed by erosion preceding deposition of the main body of the Dawson Arkose."

Trimble and Machette (1979a) continued the use of Dawson Formation and mapped an "Upper part, Paleocene and Upper Cretaceous, TKda" and "Lower part, Cretaceous, Kda") following the usage of Scott and Wobus (1973). In the Denver area (Trimble and Machette, 1979b) retained the name Arapahoe Formation but lumped this unit with the Dawson Formation as a combined Dawson and Arapahoe Formations "TKda" of Paleocene and Upper Cretaceous age. On their correlation of map units the combined TKda unit is shown as equivalent to the Denver Formation, Tkd, also of Paleocene and Upper Cretaceous age.

Bryant and others, 1981, formally re-instituted the use of the Arapahoe Formation (Ka), Upper Cretaceous, for the basal part of the Denver Basin section on the Denver 1° x 2° map sheet. They show the Arapahoe Formation as partly equivalent to the lower parts of both the Denver Formation (Tkd) and the Dawson Arkose (fine-grained sandstone, carbonaceous shale, and lignite facies, $TKd_l$). The Dawson Arkose (Td and Tdb) is shown in inter-fingering facies relationship with the $TKd_l$ facies of the Dawson Arkose, with the Denver Formation (Tkd), and with the Green Mountain Conglomerate (Tgm), Paleocene, of LeRoy (1946), Smith (1964), and Scott (1972).

Raynolds (1997, 2002) and Raynolds and Johnson (2003) have taken another approach to the “Gordian knot” of terminology and inter-fingering subdivisions in the Upper Cretaceous and Tertiary strata of the Denver Basin reviewed above. Raynolds (1997) proposed a “new stratigraphic framework for Laramide synorogenic strata”, and defined two new unconformity-bounded units, D1 and D2. The D1 unit contains all the strata between the top of the Cretaceous Laramie Formation, an unconformity surface easily recognizable in the field and on subsurface logs, and the “base of the prominent regional paleosol series first identified by Soister and Tschudy (1978)”. This paleosol was thought to lay just above an “unconformity representing approximately five to eight million years not represented by rock”, in other words a hiatus of five to eight million years. The D2 unit was defined as the strata between the unconformity associated with the Soister and Tschudy’s paleosol and the “unconformity beneath the Wall Mountain Tuff”. The D1-D2 subdivision and terminology has been useful in understanding the subsurface geology of the Denver Basin, which is relatively poorly understood from electric logs in water and petroleum wells.

The presence of a major, late-Paleocene hiatus in the Denver Basin was supported by the palynological work of Nichols and Fleming (2002). Nichols (2003) commented that the Paleocene pollen record in the Denver Basin is largely incomplete, as there have been no reports of pollen from the late Paleocene P4, P5, and lower P6 pollen zones.

The “Alexandrian solution” proposed by Raynolds (1997, 2002), has been widely adopted by many investigators in the Denver Basin (see Johnson and others, 2002, 2003, and the many papers therein). This solution has proved to be an over-simplification of the problem. The D1-D2 solution works sufficiently for interpretation in the subsurface, where stratigraphic units are identified by their characteristics on electric logs from petroleum or water wells, usually resistivity logs in the Denver Basin units younger than the Laramie Formation. However in surface mapping geology, on which Plates 1 and 2 is based, the D1-D2 solution lumps together widely different and distinct lithologic units that can be mapped as formations meeting the classical definition (“... a body of rock characterized by lithologic homogeneity; it is prevailingly but not necessarily tabular and is mappable at the earth’s surface or traceable in the subsurface” (Code of Stratigraphic Nomenclature, American Association of Petroleum Geologists Bulletin, v. 45, no. 5, [May 1961] p.645-660.) This objection does not make the D1-D2 concept any less useful, for the purpose for which it was proposed. However, by definition the boundary between D1 and D2 units is based on the recognition of a regional unconformity that is linked to the regional Denver Basin paleosol. Unfortunately that unconformity may not be truly regional in extent and the paleosol appears to not be present across the entire basin.

This was the geological situation present as the Colorado Geological Survey mapped the area between Colorado Springs and Denver between 1999 and 2007. The locations of CGS quadrangle maps and the references to their authors are shown on figure 1. This report, and the compiled geology on Plate 1 and 2, is a summary of that work.

# PRESENT STRATIGRAPHIC TERMINOLOGY

As a result of many investigations into the geology of the Denver Basin in the last decade, some summarized in this report, others summarized in a series of articles published in Rocky Mountain Geology (Johnson and others, 2002, 2003), and including a major set of Denver Basin cross sections forthcoming from the Colorado Geological Survey (Barkmann and others, in press) and further including a major proposed joint publication on the geology of the Denver Basin by the Colorado Geological Survey and the Denver Museum of Nature & Science, it has been decided that the name “Dawson” has been over-used and used indiscriminately. At a meeting on March 17, 2011 a consensus was reached by those present (Jon P. Thorson, Peter Barkmann, Matt Sares, Dave Noe (CGS); Marieke Dechesne (DMNS); and Vince Matthews (CGS, by teleconference) that the name “Dawson” should be restricted to the upper unit of the Denver Basin section. This portion of the section, largely equivalent to Raynolds (1997, 2002) D2 sequence, will herein be called the Dawson Arkose. All other usage of the name “Dawson” will be discontinued. This usage restricts the name Dawson Arkose, as much as possible, to that initiated by Richardson (1915) when he first used the name. The type locality of the Dawson Arkose remains at Dawson Butte, as designated by Richardson (1915), but is restricted to the section of arkosic sandstone on Dawson Butte (sec. 6, T. 8 S., R. 67 W.) above the regional Denver Basin paleosol described by Farnham (2001) and Farnham and Kraus (2002) and below the unconformity at the base of the Castle Rock Conglomerate. Excellent exposures of these strata can be seen in gullys on the flanks of Dawson Butte.

Consequent to the above decision it was also accepted that the entire group of synorogenic strata in the Denver Basin should be re-named the Denver Basin Group (**figure 4**). The Denver Basin Group includes both of Raynolds’ (1997, 2002) unconformity bounded sequences across the entire basin. In the Denver area and northern part of the basin the Denver Basin Group is subdivided into Arapahoe Formation, Denver Formation, and Dawson Arkose, in ascending order. In the Colorado Springs area a series of new formations have been named; Pikeview Formation, Pulpit Rock Formation, Jimmy Camp Formation, Black Squirrel Formation in ascending order, overlain by the Dawson Arkose. Thus, the name for any stratigraphic unit in the Denver Basin is not repeated, and there is only one “Dawson”.

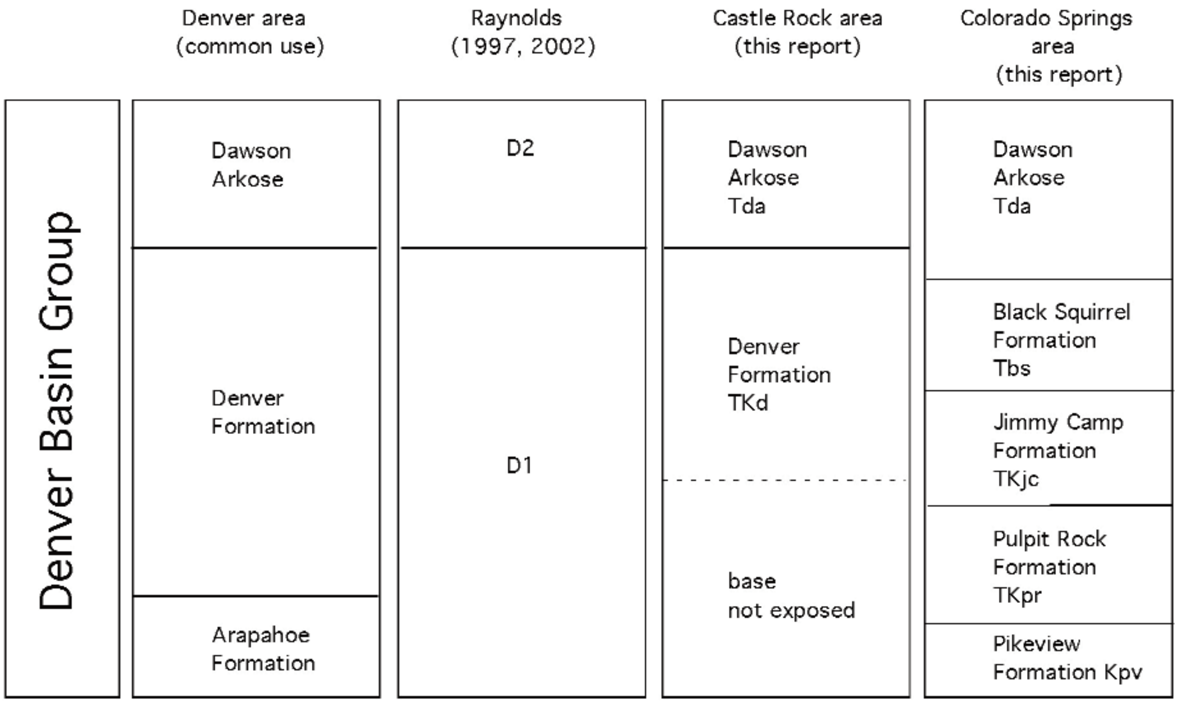



**Figure 4. Stratigraphic nomenclature used in this report, and its relationship to the common usage in the Denver area, and to the D1-D2 synorogenic sequences proposed by Raynolds (1997, 2002).**

# DENVER BASIN GROUP, NEW UNIT (UPPER CRETACEOUS, PALEOCENE AND EOCENE)

The Denver Basin Group (figure 4) is defined as the sequence of synorogenic strata lying above the unconformity at the top of the Laramie Formation, and below the unconformity at the base of the Eocene units, Larkspur Conglomerate, Wall Mountain Tuff, or Castle Rock Conglomerate. This Group is the Laramide synorogenic record of the rise and unroofing of the Front Range, deposited in inverted order as sediments within the Denver Basin. In many places in the Denver Basin this Group may include an unconformity that separates it into two sequences named D1 and D2 by Raynolds (1997, 2002). In the Denver area, and the northern part of the Denver Basin, the Denver Basin Group includes the Arapahoe Formation, Denver Formation, and Dawson Arkose, in ascending order.

In the Colorado Springs area, and southwestern part of the Denver Basin, the Denver Basin Group includes the newly named Pikeview Formation, Pulpit Rock Formation, Jimmy Camp Formation, Black Squirrel Formation, and the Dawson Arkose, in ascending order. The rational for establishing a newly named unit of Group status is explained in the preceding section "Present Stratigraphic Terminology".

The new formations in the Colorado Springs area have been previously been mapped as facies units, but are now recognized to qualify as new formations. The andesitic basal unit previously called the "lower part of the Dawson Formation" by Scott and Wobus (1973, Kda) is now recognized as the Pikeview Formation (Kpv). The Pulpit Rock facies unit, TKpr ($TKda_1$ of preliminary maps), and Jimmy Camp facies unit, TKjc ($TKda_2$ of preliminary maps) are herein named the Pulpit Rock and Jimmy Camp Formations, and have map symbols of TKpr and TKjc, respectively. Some of the preliminary maps in the Colorado Springs area included a unit above the Jimmy Camp Formation (Tkjc) that was tentatively identified as the Denver Formation. This unit has been named herein as the Black Squirrel Formation (Tbs).

A facies unit similar to the Black Squirrel Formation, (mapped north of the Palmer Divide as $TKda_4$ on preliminary maps), is recognized as a unit of consistent lithologic character that can be traced continuously from just north of the Palmer Divide to the southern Denver metropolitan area. North of the Palmer Divide the name Denver Formation has been retained for this unit. Cross section A-A' on Plate 3 indicates that the Black Squirrel Formation is probably equivalent to part of the Denver Formation.

The Dawson Arkose, Tda, ($TKda_4$ and $Tkda_5$ of the preliminary maps in the Colorado Springs area and $TKda_5$ and $TKda_6$ on preliminary maps north of the Palmer Divide) is here restricted to the section dominated by light colored, thick bedded arkose and arkosic sandstone at the top of the section, where it makes a mapable unit that can be traced throughout the area of Plate 1 and 2.

## COLORADO SPRINGS AREA

In the Colorado Springs area the Dawson Formation, as used by Scott and Wobus (1973) and Trimble and Machette (1979a), was divided into a lower part, Kda, that was simply called the "lower part of the Dawson Formation" and an upper part, TKda. For this work, the lower part is used as those authors mapped the unit (figure 4), but has been named the Pikeview Formation and given a map symbol Kpv.

The upper part was further subdivided into five litho facies map units that have herein been given names as new formations; Pulpit Rock Formation TKpr ($TKda_1$ on preliminary maps), Jimmy Camp Formation TKjc ($TKda_2$ on preliminary maps), and Black Squirrel Formation designated as $TKda_3$, on preliminary maps (Thorson and others, 2001, Thorson and Madole, 2002; Madole and Thorson, 2002; Madole, 2003, Thorson, 2003). Since those preliminary subdivisions, it has been determined that facies unit $TKda_3$ is equivalent to, and lithologically very similar to, rocks mapped as part of the Denver Formation (TKd) farther to the north from the Palmer Divide to Denver. It has also been recognized that facies units $TKda_4$ and $TKda_5$ of the preliminary maps are equivalent to, and lithologically similar to, the Dawson Arkose farther to the north. In this report, and on the map that accompanies it (Plate 1 and 2), these two facies units ($TKda_4$ and $TKda_5$) are designated as Dawson Arkose (Tda).

The Pulpit Rock Formation (TKpr) occurs as a very thick "basin edge" deposit close to the mountain front in the northwestern part of Pikeview, northeastern Cascade, and Palmer Lake quadrangles. In the eastern part of the Pikeview and eastward into Elsmere quadrangle the Pulpit Rock member thins toward the east as it inter-fingers with the Jimmy Camp Formation (TKjc). The lower part of the Jimmy Camp Formation in the Elsmere quadrangle (about 350 ft) is fairly fine-grained and appears to have a basinal (distal) relationship to the Pulpit Rock Formation. Above this lower fine-grained part, the Jimmy Camp Formation becomes coarser and contains pebbly sandstone and pebble conglomerate beds. The top of the Jimmy Camp Formation appears to inter-finger with the Black Squirrel Formation (Tbs), and the western edge of both the Jimmy Camp Formation and the Black Squirrel Formation inter-finger with the Pulpit Rock Formation along the mountain front. The coarser arkoses of the Dawson Arkose (Tda), deposited across the entire basin and continuous from the Colorado Springs area north through Castle Rock to the southern edge of the Denver metropolitan area, represent a rejuvenation of the source area and increase in stream energy late in the history of the Basin. Contacts between map units within the basin are probably both gradational and inter-fingering. **Figure 5** illustrates the facies relationship between these units.

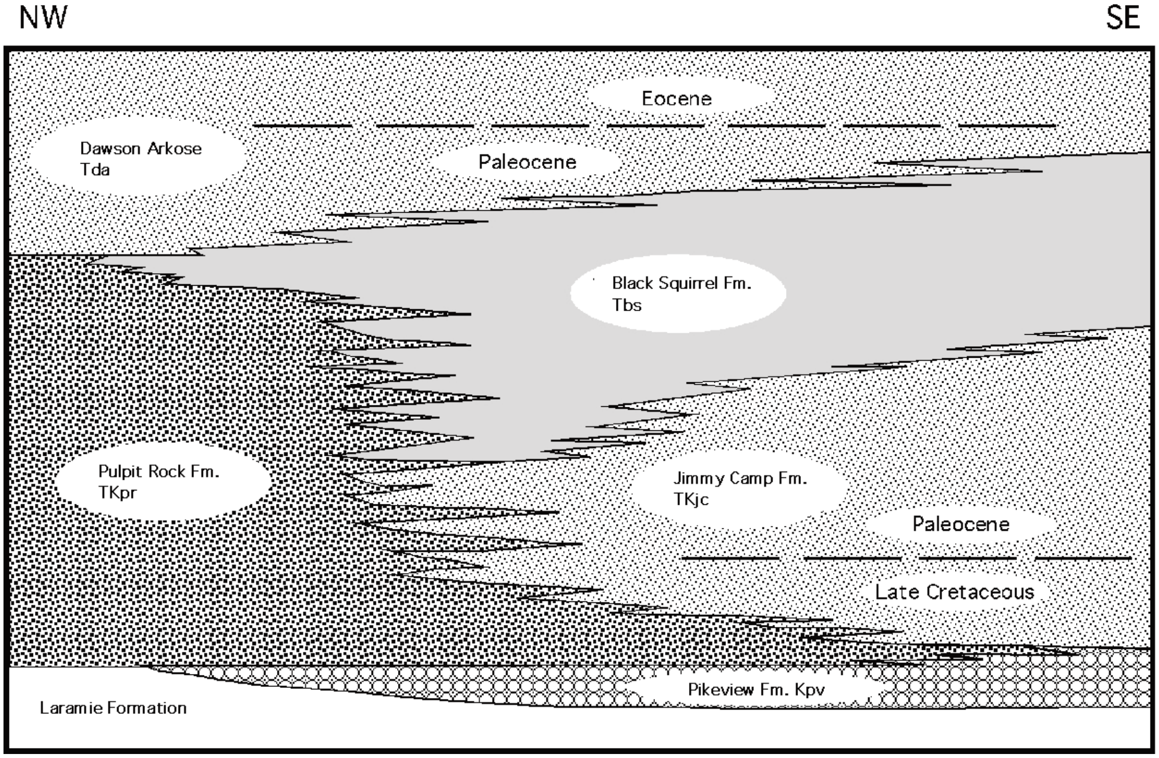



**Figure 5. Facies diagram for the Colorado Springs area, constructed to extend roughly NW-SE from the Palmer Lake quadrangle across the Elesmere Quadrangle, and to illustrate the relationships between members of the Dawson Formation of Scott and Wobus (1973); new nomenclature used in this report is illustrated in figure 4.**

Several salient points are illustrated:

a. The dominantly andesitic lowermost part of the Denver Basin Group (Pikeview Formation, Kpv) was uplifted and eroded along the mountain front so that the Pulpit Rock Formation was deposited directly onto the Laramie Formation; the source of the Pikeview Formation was southwest of the basin.

b. The Pulpit Rock Formation (TKpr – $TKda_1$ on preliminary maps) was deposited as tongue of light colored arkose and pebbly arkosic sandstone that extends into the basin, and as a basin margin unit along the mountain front; the source of this unit was granitic material from the west.

c. The Jimmy Camp Formation (TKjc - $TKda_2$ on preliminary maps) was deposited as a tongue of mixed granite-andesite debris introduced into the basin from the south; the two closely constrained locations for the K-T boundary in the Colorado Springs area occur in the lower part of this unit.

d. The Black Squirrel Formation (Tbs - $TKda_3$ on preliminary maps south of the Palmer Divide) interfingers with all of the other units, and appears to have had multiple sources.

e. The Dawson Arkose (Tda - $TKda_4$ and $TKda_5$ on preliminary maps south of the Palmer Divide) is dominated by light colored arkose and arkosic sandstone whose source was to the west; regionally this unit contains the Paleocene – Eocene boundary, which is still unconstrained in the Colorado Springs area.

The “upper part of the Dawson Formation” (as used by Scott and Wobus, 1973, and here mapped as the Jimmy Camp Formation) spans the Cretaceous-Tertiary boundary. Kluth and Nelson (1988) confirmed the Late Cretaceous (late Maastrichian) age for the upper part of the Dawson Formation on the U.S. Air Force Academy. Kluth and Nelson’s locations are now included in the Pulpit Rock Formation (TKpr) on Plate 1.

Through the work of the Denver Museum of Nature & Science (DMNS) the location of the K/T contact has been narrowed to about 100 feet of strata on Jimmy Camp Creek in the southern part of sec. 3, T. 14 S., R. 65 W. (K.R. Johnson, DMNS, personal commun., 2001). This location is now recognized to occur in the Jimmy Camp Formation, see Plate 1. Another approximate location for the K-T boundary has been found on Cottonwood Creek about 1000 feet downstream from Rangewood Drive (SE¼ sec. 10, T. 13 S., R. 66 W., Ian Miller, DMNS, personal commun. 2007). This location is also within the Jimmy Camp Formation, see Plate 1.

Above these approximate locations of the K-T boundary, the Paleocene age of the upper part of the Jimmy Camp Formation and the Black Squirrel Formation has been confirmed by fossil collections on Jimmy Camp Creek in the Elsmere quadrangle (DMNH # 2124, 2131, 2132, 2133, and 2174, Jimmy Camp formation); on Cottonwood Creek and near the intersection of Templeton Gap Road and Woodmen Road in the Falcon NW quadrangle (K.R. Johnson, DMNS, personal commun., 2006, Black Squirrel Formation), and along Monument Creek in the Monument quadrangle (DMNH # 1204 and 2177, Pulpit Rock and Black Squirrel Formations, respectively). Eberle (2003) has discussed the occurrence of Puercan (early Paleocene) mammalian fossils from the Corral Bluffs quadrangle (immediately east of the area of Plate 1) from strata that are here included in the Jimmy Camp Formation.

Recent palynological identifications by Douglas Nichols (2007, written commun.) on samples from the Monument quadrangle collected for this work confirm that the Black Squirrel Formation contains some Paleocene pollen zone P3, and that the Dawson Arkose (Tda) in the Monument quadrangle began deposition in Paleocene pollen zone P4 (for more information on these new pollen discoveries see the later sections describing the Black Squirrel Formation and the Dawson Arkose).

All of the above evidence indicates that deposition of the Jimmy Camp Formation began in the Late Cretaceous and extended into the Paleocene. By analogy, since the Pulpit Rock Formation interfingers with the Jimmy Camp Formation, part of the Pulpit Rock Formation must also span the Cretaceous-Tertiary boundary. The Black Squirrel Formation is thought to be mostly Paleocene, if not entirely, Paleocene.

### Pikeview Formation (Kpv) New Unit - Upper Cretaceous

The Pikeview Formation, the lowest formation in the Denver Basin Group, is mostly greenish-gray to olive-brown pebbly sandstone and pebble conglomerate, almost exclusively composed of andesitic material, interbedded with grayish-green to dark-green and brown to brownish-gray siltstone and sandy claystone. This unit, hearin named the Pikeview Formation, is best exposed in the Pikeview quadrangle (Thorson and others, 2001, mapped therein as the unit Kda). The Pikeview Formation is named for the Pikeview area of northern Colorado Springs, an old coal mining settlement that has disappeared into suburban development. The "K" in the map symbol designation, Kpv, has been retained to remind us that this unit is wholly Upper Cretaceous in age.

The unit has been projected across the northeastern-most part of the Colorado Springs quadrangle, and mapped in the Elsmere quadrangle (Madole and Thorson, 2002, also there mapped as the unit labeled Kda). In the Elsmere quadrangle the Pikeview Formation is finer-grained and orange weathering, yellowish-green and greenish-gray to olive-brown sandstone almost exclusively composed of andesitic material, interbedded with grayish-green to dark-green and brown to brownish-gray siltstone and sandy claystone.

The sandstone and pebble conglomerate in most of the Pikeview Formation is thick to very thick bedded, massive or cross-bedded, and appears to be amalgamated bodies of braided-stream fluvial channels. These units characteristically contain sub-round-to-round pebbles up to 3 inches in diameter in a poorly sorted matrix of medium- to very coarse-grained sand (**figure 6a, 6b**). Pebble lithology is predominantly andesite with only rare fragments of quartz, chert, or pink granite. Carbonized wood fragments, as large as logs up to 12 in. in diameter and 8 ft long, are common in the sandstone channels. The sandstone often contains rip-up clasts of finer lithologies, occasionally as large as 3 ft in diameter in thick channels with coarse pebbles. In a very well-exposed section along the south bank of Cottonwood Creek, about 300 feet upstream from the Vincent Drive bridge (SW¼SW¼ sec. 8, T. 13 S., R. 66 W.) very thick, cross-bedded or massive, coarse pebbly sandstone beds contain large rounded clasts of olive-brown siltstone and sandy claystone which appear to be eroded fragments of the upper transition member of the Pierre Shale or some of the finer beds in the Fox Hills Sandstone. Two of these clasts contained small, highly polished, phosphate pebbles or nodules, which are characteristic of the upper Pierre Shale and Fox Hills Sandstone. One of the thick sandstone beds in this section also contains the ripped up stumps of palm trees, which can be identified by their characteristic root structure (**figure 7**).

The finer grained units are very thin to medium bedded and are finely laminated to massive. Occasional ripple laminations are seen. The beds of grayish-green to dark-green clayey siltstone and sandy claystone commonly have brown plant fragments on bedding planes. Well preserved fossil leaves of several species were found along the north bank of Cottonwood Creek in SW¼SW¼ sec. 8, T. 13 S., R. 66 W., about 300 feet west of the Vincent Drive bridge. Beds of brownish-gray siltstone and brown to black, organic-rich sandy claystone are common near the top of the Pikeview Formation, especially in the transition with the overlying Pulpit Rock Formation.

Locally at the base of the unit there are lenticular beds of light-gray, medium- to coarse-grained, quartzose pebbly sandstone or yellowish-gray to orange chert-pebble conglomerate. The lenses of quartzose pebbly sandstone or conglomerate in the base of the Pikeview Formation are exposed in three places in the Pikeview quadrangle (Thorson and others, 2001). On a small hill near the west entrance to the UCCS campus from Austin Bluffs Parkway (NE¼NW¼ sec. 29, T. 13 S., R. 66 W.) about 8 feet of yellowish-gray to orange chert-pebble conglomerate is poorly exposed. The red, yellow, and black chert fragments in the conglomerate are sub-angular to sub-round and up to 1 1/2 inches in diameter.

Also exposed on the UCCS campus, in bold outcrops below Columbine Hall, are pebbly sandstone beds that appear to be the base of the Pikeview Formation, but the lower contact are not exposed. This sandstone body is at least 20 to 30 feet thick and is composed of a stacked series of sand-filled channels. The channels were filled with complexly

**Figure 6a. Pikeview Formation (Kpv) outcrop along Cottonwood Creek about 300 feet upstream from the Vincent Street bridge (SW¼SW¼ sec. 8, T. 13 S., R. 66 W.) with strongly developed cross bedding. Note two large blocks of Pierre Shale, above and to the left of the hammer, near the left edge of the photograph; hammer for scale is 15 inches long, white material in the foreground a the base of the outcrop is ice.**

**Figure 6b. Pikeview Formation (Kpv) outcrop along Cottonwood Creek about 300 feet upstream from the Vincent Street bridge (SW¼SW¼ sec. 8, T. 13 S., R. 66 W.); detail of pebbly sandstone and pebble conglomerate texture, the pebbles are almost exclusively andesite (96%); hammer for scale is 15 inches long.**

**Figure 7. Palm stump in a block of eroded Pierre Shale in the outcrops of the Pikeview Formation (Kpv) along Cottonwood Creek near the Vincent Street Bridge (SW¼SW¼ sec. 8, T. 13 S., R. 66 W.); most of the stump has been eroded and filled with pebble conglomerate; only part of the bark remains, but the root structure characteristic of palm trees is clearly visible in the remaining fine-grained yellowish-gray Pierre Shale. Image is about 24 inches wide.**

cross-bedded medium- to very coarse-grained, light-gray to buff sandstone in thick to very thick beds. The sand grains are sub-angular to sub-round, and mostly quartz with about 5 per cent to 7 per cent sand-size chert grains. The basal parts of the cross-bedded units are often pebbly sandstones with sub-angular to sub-round red, yellow, or black chert pebbles up to 1 1/2 inch in diameter. White silicified wood fragments are also found in a few places in this outcrop as well as the mold impression of a small log about 5 inches in diameter and 6 ft long.

An exposure of similar buff, cross-bedded pebbly sandstone with chert pebbles and petrified wood fragments occurs at the base of the Pikeview Formation in Pulpit Rock Park NW¼SW¼ sec. 17, T. 13 S., R. 66 W (**figure 8**). Here the erosional contact with the underlying Laramie Formation is exposed. The upper part of the Laramie Formation is very-fine to fine-grained brownish-gray sandstone with ripple cross-laminations and abundant fine organic material, overlain by about eight feet of dark-brown sandy claystone. Resting unconformably on this claystone unit, on a scoured surface, is about three to four feet of buff fine- to medium-grained sandstone with cross beds, layers of chert pebble conglomerate, and abundant fragments of fossilized wood. This thin basal sandstone is overlain by thick beds of andesite pebble conglomerate and andesitic pebbly sandstone of the Pikeview Formation, with well-rounded pebbles up to one and one-half inches in diameter.

Lenses of quartzose pebbly sandstone or pebble conglomerate in the base of the Pikeview Formation are poorly exposed on the west side of the valley of Jimmy Camp Creek just north of Highway 94 in the Elsmere quadrangle.

These beds, or channel fills, of pebbly sandstone containing common chert fragments may be the local equivalent of the Arapahoe Formation conglomerates mapped further north along the western edge of the Denver Basin. In the southwestern part of the Denver Basin these cherty lithologies are not thick or common enough to carry as a separate map unit at 1:24,000 scale however.

Several thin beds of coal and dark brown coaly shale occur in an excellently exposed outcrop of the fine facies of the Pikeview Formation along the east bank of Jimmy Camp

**Figure 8. Outcrop of the basal sandstone unit of the Pikeview Formation (Kpv) in Pulpit Rock Park (NW¼SW¼ sec. 17, T. 13 S., R. 66 W.). The dark-brown claystone in the foreground is the uppermost part of the underlying Laramie Formation; the buff cross-bedded sandstone layer is the lowermost unit of the Kpv unit as mapped in the Pikeview quadrangle. The slope immediately above the sandstone ledge is andesite pebble conglomerate. Hammer for scale is 15 inches long.**

Creek just upstream from Highway 94 (SE¼ SE¼ Sec. 9, T. 14 S., R. 65 W.). This section also contains small clastic dikes of light gray sandstone and the petrified stumps of small trees that were buried upright, in growth position. A bed of altered apparent tuffaceous material that is waxy textured grayish-green claystone with small white crystals of altered feldspar and small black flakes of biotite also occurs in these Jimmy Camp Creek exposures. Samples of this material were sent by the Denver Museum on Nature & Science to John Obradovich at the U. S. Geological Survey for possible radiometric dating; so far results have been negative.

The thickness of the Pikeview Formation varies from 0 to perhaps as much as 240 feet. A nearly complete section of about 210 feet of the Pikeview Formation is exposed on the western end of the UCCS campus (NE¼NW¼, sec. 29, T. 13 S., R. 66 W.). In the vicinity of Pulpit Rock Park (SW¼ sec. 17, T. 13 S., R. 66 W.) the Pikeview Formation is about 200 feet thick. The unit thins to the southeast along its outcrop trend in the Pikeview quadrangle until the formation is only about 120 feet thick in Palmer Park (NE¼NW¼ sec. 33, T. 13 S., R. 66 W.). To the northwest this unit also thins rapidly until it is unconformably missing in the steeply dipping section at the head of Woodmen Valley (SE¼ sec. 3, T. 13 S., R. 67 W.), where the Pulpit Rock Formation was deposited directly over an unconformity cut on the eroded edge of the upper member of the Laramie Formation.

The top of the Pikeview Formation is well exposed in the Pikeview quadrangle. Good examples of this contact can be found in gullies at the base of the Pulpit Rock Formation cliff in S½ sec. 11, T. 13 S., R. 67 W.; in Pulpit Rock Park on the north side of an unnamed west-flowing tributary to Monument Creek (N½ SW ¼ sec. 17, T. 13 S., R. 66 W.); on the west face of Pulpit Rock and continuing to the southeast along the base of the cliffs formed by the Pulpit Rock Formation; on the UCCS campus, particularly in gullies behind (above) the buildings named “The Lodge” and “Breckenridge House”; and in Palmer Park in NW¼NE¼, sec. 33, T. 13 S., R. 66 W. In these exposures the uppermost beds of the Pikeview Formation are thick to very thick beds of massive, olive to yellowish-green, clay-rich sandstone containing common plant fragments. These sandstone beds contain sticky, greenish, montmorillonitic clays derived from weathering or alteration of the andesitic debris and are typical of the upper part of the Pikeview Formation. A few thinner beds of dark-brown coaly shale are interbedded with the yellowish-green and olive-colored uppermost beds of the Pikeview Formation. Above the yellowish-green clayey beds there is commonly 20 to 30 ft of thin beds of brown organic-rich siltstone and brown fine- and very fine-grained quartzose sandstone with a few interbedded, light-gray, coarse arkosic beds. This change in lithology from clayey andesitic rocks to quartzose and arkosic rocks is the contact between the Pikeview and Pulpit Rock Formations.

The age of the lower part of the Denver Basin Group is considered by Varnes and Scott (1967) and Scott and Wobus (1973) to be Late Cretaceous. That age assignment was confirmed by Kluth and Nelson (1988) who found late Maastrichtian (latest Upper Cretaceous) pollen in arkoses of the upper part of their Dawson Formation, at localities now mapped as Pulpit Rock Formation, on the U.S. Air Force Academy.

The depositional environment indicated by the sandstone beds in the Pikeview Formation is a very energetic fluvial system capable of moving large volumes of andesitic pebbles, logs, and boulders up to 3 feet in diameter. Sedimentary structures in the sandstone beds indicate that this system was dominated by braided streams. The coarse debris, braided streams, and erosional power indicated by clasts of Pierre Shale or Fox Hills Sandstone suggest deposition close to the rapidly rising mountain front. In the Pikeview quadrangle the finer deposits of siltstone and sandy claystone with leaf fossils, interbedded with the braided stream deposits, suggest that the depositional location was probably a forested, relatively low-slope complex of coalescing alluvial fans. A greater proportion of finer deposits characteristic of flood plains and swamps should be expected farther eastward, into the Denver Basin, while coarser deposits could be expected closer to the mountain front, if they had not been removed by erosion.

On the west side of the Pikeview quadrangle (sec. 3 and 11, T. 13 S., R. 67 W.) a profound local unconformity exists between the upper member of the Laramie Formation and the Pulpit Rock Formation. The entire Pikeview Formation and much of the upper member of the Laramie Formation were removed as the unconformity was cut. Clasts of upper Pierre Shale and Fox Hills Sandstone that are present in the Pikeview Formation in the Cottonwood Creek locality indicate that Fox Hills and Pierre strata were exposed as the Pikeview Formation was being deposited. On the basis of the rarity of granitic fragments in the Kpv unit, one can interpret that erosion had not yet exhumed basement rocks from beneath a carapace of Late Cretaceous andesite volcanics. This unconformity has been mapped farther to the northwest by Varnes and Scott (1967), in the southwest corner of the U.S. Air Force Academy, where the Dawson Arkose rests unconformably on Fox Hills Sandstone. Kluth and Nelson (1988) remapped the area of Varnes and Scott's unconformity and demonstrated that the upper part of their "Dawson Formation" (now mapped as Pulpit Rock Formation) rests unconformably on the Pierre Shale as well.

The pebbles in pebbly sandstone or pebble conglomerate in the Kpv unit are almost exclusively pyroxene andesite. Stream flow directions measured in these coarse-grained beds indicate that streams carrying the andesite pebbles came from the southwest. The andesite pebbles of the Kpv unit are chemically distinct from volcanic pebbles in other units with superficially similar volcanic pebbles, specifically the Jimmy Camp Formation (TKjc) and the Denver Formation (TKd) on the west side of the Denver metropolitan area. The subject of chemistry and provenance of volcanic pebbles in the southwestern Denver Basin is discussed at greater length in a later section of this report.

Several swarms of small clastic dikes were found in the Pikeview Formation in outcrops along Cottonwood Creek, Monument Creek, Jimmy Camp Creek, and Sand Creek. Clastic dikes are generally created by either rapid loading of soft sediments or as sand "blows" associated with earthquakes. It is interesting to note that the northeast orientation of clastic dikes intruding the Late Cretaceous Pikeview Formation is markedly different from northwesterly orientations of similar dikes intruding the later deposited Jimmy Camp Formation.

Cottonwood Creek: One dike swarm is located about 200 feet downstream from the Vincent Drive bridge (SW¼SW¼ sec. 8, T. 13 S., R. 66 W.), where outcrops of dark green sandy claystone in the creek bottom are usually covered with water. These dark beds are cut by a north east-trending swarm of small dikes, up to 3/4 inch thick, which are filled with light-gray silt and clay. A similar swarm with NE trends occurs about 1200 ft upstream from the Vincent Street Bridge in SE¼SW¼ sec. 8. A third swarm of thicker and coarser sand dikes were found further upstream on Cottonwood Creek (about 1800 feet east-southeast of the Vincent Drive bridge, SE¼SW¼ sec. 8, T. 13 S., R. 66 W.) near the top of the Kpv unit. At this locality 4- to 6-inch-wide dikes of light-gray, coarse to very coarse sandstone intrude outcrops of green sandy claystone in the bottom of the creek. Most of the dikes in this swarm strike between N45°E and N55°E, but one of the dikes bifurcates with one branch that strikes approximately E-W. The strike directions of 53 clastic dikes measured along Cottonwood Creek averages N52°E.

Monument Creek: Thin clastic dikes of fine- to medium-grained gray sandstone (similar to those on Cottonwood Creek) also occur in an eroded cutbank along Monument Creek about 1000 ft upstream from the bridge where Woodmen Road crosses Monument Creek (SW¼NE¼ sec. 7, T. 13 S., R. 66 W.). These clastic dikes also trend northeasterly; the strike of 17 dikes averages N52°E.

Jimmy Camp Creek: In the Elsmere quadrangle, in the cutbanks on the east side of Jimmy Camp Creek about 1000 ft upstream from Highway 94 (SE¼SE¼ sec. 9, T. 14 S., R. 65 W.), and in a nearby series of small gullies tributary to Jimmy Camp Creek (SW¼SW¼ sec. 10, T. 14 S., R. 65 W.), another swarm of northeast trending clastic dikes are exposed. Here the strike direction of 19 dikes averages N62°E. These dikes occur in association with the partially petrified stumps of small trees that were buried in upright growth position.

Sand Creek: Thin clastic dikes were also found along Sand Creek in the Elsmere quadrangle, about 800 feet upstream from Galley Road (SE¼NE¼ sec. 12, T. 14 S., R. 66 W.) in small creek-bank and creek-bed outcrops of the uppermost part of the Kpv unit too small to show on the geologic map. At this location the strike of 16 dikes averages N58°E.

As part of a National Science Foundation funded research project on the provenance and chemistry of the volcanic pebbles in the conglomerate and pebbly sandstone of the Denver Basin, I measured paleocurrent indicators and made pebble counts from the Kpv unit. Paleocurrent flow directions were measured using the orientation of the axis of trough-shaped cross bed sets. **Figure 9** shows a rose diagram for 45 measurements of paleocurrent flow directions from the Kpv unit made at various locations in the Pikeview quadrangle. They show a pronounced clustering of stream flow directions in an ENE direction, interpreted to indicate that the source of the Kpv andesite pebbles was probably to the southwest of the Colorado Springs area, and that the direction of stream flow was generally to the east-northeast.

The following figure (**figure 10**) shows the percentages of various pebble lithologies found in the Pikeview Formation (Kpv) pebble conglomerates and pebbly sandstone. Data was collected by marking a narrow band on an outcrop of Kpv pebble conglomerate or pebbly sandstone and examining any pebble larger than ¼ inch included within that band; pebbles were identified and tallied by lithology until 60 to 100 pebbles were counted from each outcrop. The upper part of figure 10 shows the percentages of lithologies

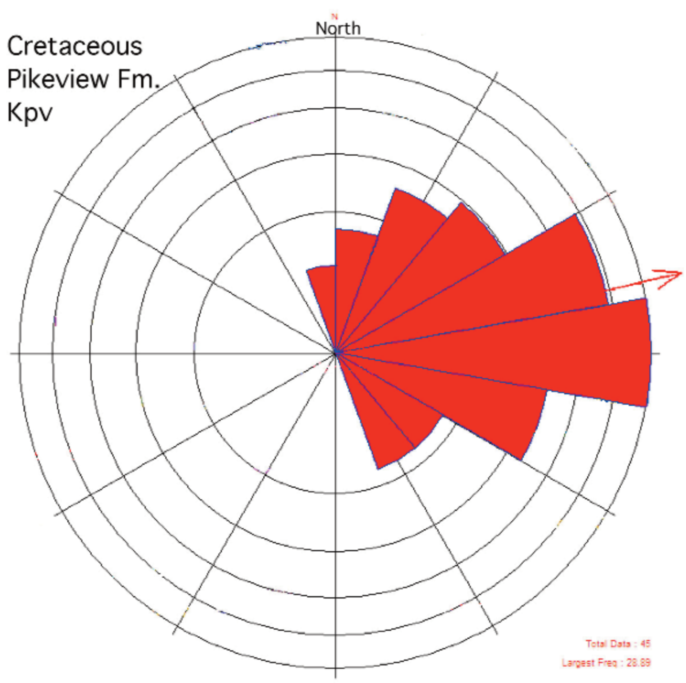



**Figure 9. Paleocurrent measurements for the Pikeview Formation (Kpv) in the Pikeview quadrangle; measurements collected from seven locations; number of measurements, 45; average direction (arrow) 74 degrees (N74°E).**

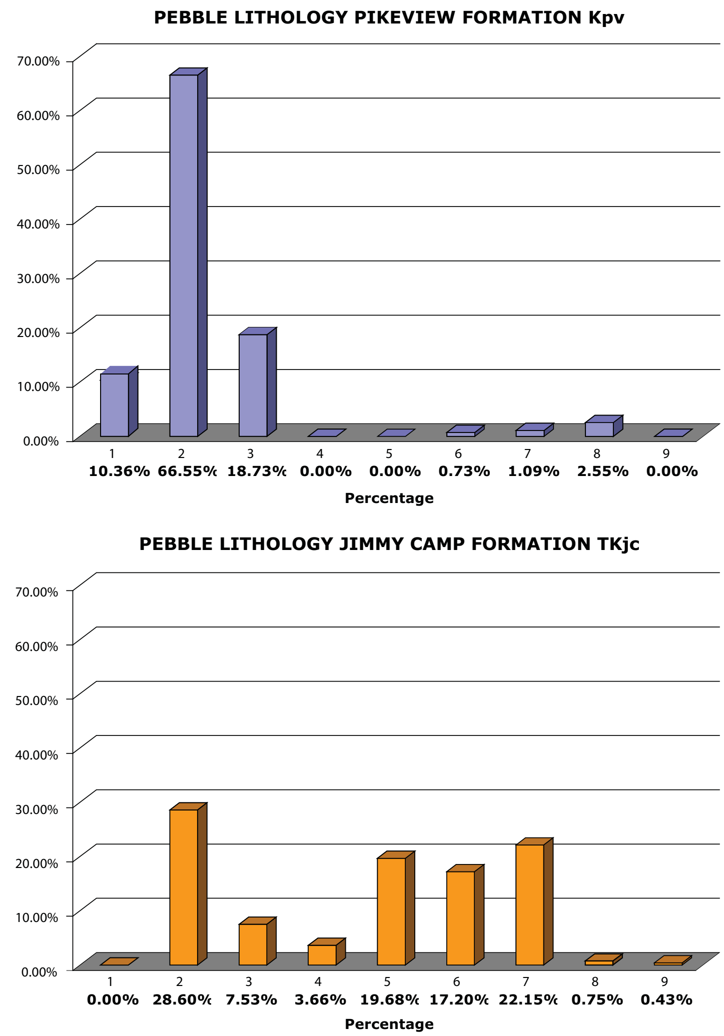



**Figure 10. Comparison of the percentage of various pebble lithologies in the Pikeview (Kpv) and Jimmy Camp (TKdjc) Formations. The pebbles in the Kpv unit were derived from a source that was almost exclusively andesite (96%, lithologies 1, 2, and 3); the pebbles in the Jimmy Camp Formation were derived from a mixed source that contained andesite (36%, lithologies 1, 2 and 3)) and dacite (3.6%, lithology 4) but was probably dominated by granite (granite, 19.7%, plus 39% combined feldspar and quartz, probably derived from weathering granite, lithologies 5, 6, and 7).**

for the Pikeview Formation. Three types of andesite were tallied in the field; #1, vesicular dark gray to black andesite; #2, fine-grained gray to greenish-gray andesite; and #3, medium to light-gray altered andesite. Those three andesite lithologies make up almost 96% of the pebbles in the Kpv unit; with insignificant amounts of feldspar, quartz, and sedimentary lithologies (shale and chert).

This analysis of the pebble lithologies in the Kpv unit indicates that the unit was derived almost exclusively from an andesitic volcanic terrane. A significant amount of the shale pebbles are identifiable as coming from erosion of the Pierre Shale, which was being truncated by erosion near the edge of the basin contemporaneous with deposition of the Pikeview Formation. The chert pebbles are similar to chert in the lower Paleozoic carbonates that now outcrop in the Manitou Springs area.

Pebble lithologies are:

1. dark gray to black vesicular andesite with olivine
2. dark green to dark gray fine grained pyroxene andesite
3. medium to light gray altered andesite
4. light gray to cream biotite dacite
5. granite
6. feldspar
7. quartz
8. shale and chert (Pierre and Fox Hills shales, Paleozoic cherts)
9. other (mostly fossil bone and wood)

The single best location to examine the lithologies and bedding characteristics of the Pikeview Formation are in the exposures along Cottonwood Creek above and below the Vincent Street bridge (SW¼ sec. 8, T. 13 S., R. 66 W.). Here the volcanic pebbles in the conglomerate beds are as large as 3 inches. This section, along Cottonwood Creek, is designated as the type locality for the Pikeview Formation. A second good exposure, with a much finer-grained and more distal aspect, is located on Jimmy Camp Creek in the Elsmere quadrangle, upstream from the Highway 94 bridge (SE¼ sec. 9 and SW¼ sec 10, T. 14 S., R. 65 W.).

The sandstones in the Pikeview Formation may be difficult to excavate but will probably have good foundation stability. The finer grained units are clearly the opposite, having achieved a local reputation as “green slime” for their considerable instability (D. Noe, 2000, oral communication). Because the Kpv unit is largely composed of andesitic debris, soils derived from the unit are expected to have very high amounts of swelling clays, and high swell factors, and should be treated accordingly.

### Pulpit Rock Formation (Tkpr) New Unit - Upper Cretaceous and Paleocene (TKda$_1$ on preliminary maps)

The Pulpit Rock Formation of the Denver Basin Group is dominantly composed of white, light-gray, or cream, cross bedded or massive, very coarse arkosic sandstone, pebbly arkose, or arkosic pebble conglomerate; the unit contains occasional interbeds of thin- to very thin-bedded gray claystone and sandy claystone, or dark-brown to brownish-gray, organic-rich siltstone to coarse sandstone containing abundant plant fragments. The Pulpit Rock Formation comprises the lower strata in the Cretaceous-Paleocene part of the Denver Basin Group in the eastern, basinward, part of the Pikeview quadrangle, whereas it also includes almost the entire upper part of the Denver Basin Group in the western part of the Pikeview quadrangle area, proximal to the mountain front. Northward from there, in the Cascade, Monument, and Palmer Lake quadrangles the unit makes a narrow outcrop zone along the mountain front. The unit varies in thickness from about 400 feet in the southeastern part of the Pikeview quadrangle to about 1,200 feet in the western part. In the Palmer Lake and Monument quadrangles the thickness of the unit is uncertain; its base is not exposed. Eastward into the Elsmere quadrangle the unit thins to almost zero, and disappears as an effective map unit, in the vicinity of Jimmy Camp Creek (SE¼ sec. 9, T. 14 S., R. 65 W.). Excellent bold exposures of the Pulpit Rock Formation occur as cliffs in an arcuate trend across the Pikeview quadrangle from the U.S. Air Force Academy and Woodmen Valley area through Pulpit Rock (**figure 11**), Austin Bluffs, and Palmer Park. The formation has been named for Pulpit Rock in Pulpit Rock Park (SW¼ SW¼ sec. 17, T. 13 S., R. 66 W.) a prominent landmark and popular suburban recreation area. The type section of the Pulpit Rock Formation is designated as the exposures shown in figure 11, and eastward following the ridge-line for about 1500 feet.

Six different lithofacies are present in the Pulpit Rock Formation:

1. Beds of white to light-gray very coarse arkosic sandstone, pebbly sandstone, or arkosic pebble conglomerate dominate the unit. Many outcrops have only beds of this character well exposed. These beds are generally very thick, often 8 or 10 feet, and commonly have steeply inclined cross bedding and scoured bases. The sand- and gravel-size material in this lithofacies is sub-angular to sub-round and poorly sorted. The coarse beds have irregularly distributed areas of finer grained and better sorted, more quartz-rich sandstone that is composed mostly of gray and clear, fine- to medium-grained quartz grains. Clasts of this finer, more quartzose but still arkosic, sandstone occur as ripped-up, and included, sandstone clasts in the pebble conglomerate beds. The character of the sediments and sedimentary structures of the Pulpit Rock conglomerate beds suggest deposition in energetic fluvial environments, probably braided streams. The pebbles in these coarse-grained beds are dominated by sub-round fragments of quartz up to 3 inches in diameter. Also common as clasts are pieces of recognizable white or light-gray granite and fragments of white feldspar, up to 1 1/2 inches in size. The granite and feldspar clasts commonly have perthitic and “graphic granite” textures. Minor amounts of pebbles of chert, smoky quartz, or granitic metamorphic rocks occur locally.

**Figure 11. Pulpit Rock, type locality for the Pulpit Rock Formation (TKpr, cliffy exposures) in Pulpit Rock Park (SW¼ SW¼ sec. 17, T. 13 S., R. 66 W.). The yellowish-gray exposures among the pine trees in the lower part of the image are the top of the Pikeview Formation (Kpv); the contact between the Kpv unit and the Pulpit Rock Fm. is at the base of the cliffy exposure.**

Pebbles of volcanic origin are extremely rare; their scarcity is all the more significant considering the dominance of andesitic volcanic material in the underlying Pikeview Formation (Kpv unit, see figure 10).

2. Beds of white to light-tan, fine- to medium-grained feldspathic sandstone with lower angle cross beds are often interbedded with the gravel beds, but being more friable, make up more recessive parts of the outcrops. These sandstones are poorly sorted, have high clay contents, and are often thin or medium bedded. Wavy bedding and ripple cross-laminations are common. Carbonized plant fragments are common as both disseminations and as laminae of organic material. These beds appear to be the deposits of less energetic streams or backwater areas between braided streams. Clasts of sandstone of this character occur in the conglomerate beds.

3. Massive, light-gray to light-brownish-gray, very thick, homogeneous beds with little internal structure are interbedded with the conglomerate in some areas. Close examination of these beds reveals local, poorly-developed crude grading of the coarser fragments, disseminated small dark flakes of carbonaceous organic material some of which has the cellular texture of charcoal, and a few wispy dark laminae. The matrix of these beds is very clay-rich, fine- to coarse-grained sandstone containing matrix-supported, angular to sub-round grains ranging in size from very coarse sand to pebbles. These generally structureless, massive beds appear to have originated as mudflows.

4. Interbedded with the gravel beds and mudflow beds at Pulpit Rock and many other areas are occasional dark-brown to brownish-gray organic-rich beds of siltstone to coarse sandstone with abundant plant fragments. These beds are usually structureless and commonly darkest colored at their tops. They

may grade downward into gravel or mudflow beds, but the tops are generally sharp and may have load deformation structures where overlain by thick arkosic gravel or mudflow beds. These dark beds, or dark zones at the tops of thick beds of other characteristics, are interpreted as the deposits of ephemeral swamps and swampy soil areas buried in rapidly subsiding areas of the basin (**figure 12**). Examples of each of the first four types of beds can be seen in a small area of excellent exposures at Pulpit Rock and the ridge which extends east-southeast from Pulpit Rock (figure 11; SW¼SW¼ sec. 17, T. 13 S., R. 66 W.).

5. In many outcrops of Pulpit Rock Formation, occasional beds of thin- to very thin-bedded, light- to dark-gray claystone and sandy claystone are interbedded between thicker beds of arkosic gravel.

6. There are also numerous interbeds of 1- to 6-foot-thick, light- to dark-red, and orange paleosols in the upper part of the Pulpit Rock Formation in a zone along the mountain front extending from the northwestern part of the Pikeview quadrangle through the Monument quadrangle and into the Palmer Lake quadrangle. Westward from this zone of common paleosols, towards the mountain front and particularly well developed in the Palmer Lake quadrangle, is a basin-edge zone where large parts of the Pulpit Rock Formation are stained red, pink, or orange by extensive oxidation. Basinward, occasional paleosols occur in the Jimmy Camp Formation, and one or more prominent paleosol zones extend for a considerable distance into the basin in the Dawson Arkose.

One of the thickest and best developed paleosol beds in the Pulpit Rock Formation is exposed in the west bank of Monument Creek about 700 feet south of the sewage disposal plant on the U.S. Air Force Academy (NW¼NW¼ sec. 30, T. 12 S., R. 66 W.). Here greenish-gray, gritty claystones interbedded with thin lenses of coarse arkosic sandstone are oxidized to red and yellow-brown colors. The oxidized claystones contain small chips of dark-brown plant remains and root casts. Another example is exposed in a road cut about 400 feet west of the fire station in sec. 27, T. 12 S., R. 67 W. on the west edge of the Pikeview quadrangle.

Some of these red, pink, and orange oxidized zones have the mottling and root casts of true soil development, as in the two examples above, others are just oxidized zones,

**Figure 12. Pulpit Rock Formation (TKpr) near the intersection of Vincent Drive and Woodmen Road showing the characteristic thick to very-thick bedding units with thin interbeds of finer-grained material that are weathering out of this road cut; the dark brown beds at the lower left of the exposure are a swampy soil zone.**

usually in arkose beds, and can't be truly confirmed as paleosol. In a traverse from the sewage plant location mentioned above to the bridge where Northgate Boulevard crosses Monument Creek (NW¼ sec. 12, T. 12 S., R. 67 W.; about 3 miles), more than 50 oxidized zones were found in the Pulpit Rock Formation exposed in the creek banks. Particularly good exposures occur in high creek-side bluffs in NW¼NW¼ sec. 19 T. 12 S., R. 67 W. near the north edge of the Pikeview quadrangle, where 5 or 6 individual red oxidized zones or paleosol zones can be seen in 25 to 30 feet of light-colored arkosic sandstone beds.

The basal contact of the Pulpit Rock Formation on the Pikeview Formation (Kpv) is usually poorly exposed. An exception is at the foot of Pulpit Rock (SE corner sec. 17, T. 13 S., R. 66 W., in Pulpit Rock Park where the transitional 20 to 30 ft of strata consist of brown coaly siltstone and brown, fine- and very fine-grained quartzose sandstone with abundant plant fragments and thin laminations of organic material. Interbedded with these organic-rich beds are occasional thick beds of light-gray, coarse to very coarse or pebbly, arkosic sand similar to the arkosic beds that are characteristic of the Pulpit Rock Formation. These beds are overlain by very thick bedded, massive and cross- bedded, very coarse arkosic sandstone beds on a sharp contact. In a few places the brown quartzose sandstone beds are missing, and thick, coarse arkosic sandstone beds of facies unit one rest directly on the olive to yellowish-green, clay-rich sandstones of the uppermost Pikeview Formation. The contact between the Pikeview Formation (Kpv) and Pulpit Rock Formation (Tkpr) is placed at the change from clayey, yellowish-green, andesitic sandstone below, to more quartzose and arkosic lithologies above. Another exposure of this contact occurs along Cottonwood Creek in SE¼ SW¼ sec. 8 T. 13 S., R. 66 W., where the transition is about 20 feet of gray and dark-gray water-saturated and incompetent claystone and clayey sandstone.

Evidence for the origin of the brown, orange, and red iron-oxide-cemented layers that make curious erosional forms called "hoodoos" or "monuments" common in the white arkosic beds of the Pikeview Formation can be found in the Pikeview quadrangle. Along Cottonwood Creek, and in other occasional creek-side outcrops where down cutting has been rapid enough to expose unoxidized rocks, there is abundant iron sulfide, probably pyrite or marcasite, in the Denver Basin Group units Kpv, TKpr, and TKjc. Particularly good examples of these iron sulfide occurrences can be seen in nearly every outcrop along Cottonwood Creek from the Pikeview Formation (Kpv), through the Pulpit Rock Formation and into the lower part of the Jimmy Camp Formation. Iron sulfide occurs as disseminations in the sandstones and as spherical concretions as large as 2 to 3 inches in diameter (**figure 13, and 14**). The concretions consist of pyrite- or marcasite cemented quartz sand grains that weather out of the strata intact. Iron sulfide fills pore space in the sandstone, probably replacing the sandstone cement, and possibly partially replacing chemically reactive sand grains. In sandstone beds with high permeability and abundant woody fragments, iron sulfide has grown into flat clusters of intergrown concretions and layers of pyrite-cemented sand. These sulfide layers erode out of the soft, friable sands and litter the banks and bed of Cottonwood Creek as flat clusters of sulfide spheres which look like clusters of large grapes, or small oranges.

Sulfide balls and irregular masses in sandstones are common in many sedimentary basins in which sandstones have been subjected to reducing conditions. In the Pikeview, Pulpit Rock, and Jimmy Camp Formation sandstone beds with remaining carbonized organic matter, it is common to find that coaly material has been partially replaced by iron sulfide. These occurrences illustrate the effect of the strong chemical affinity of carbon for oxygen (Krauskopf, 1967). Carbonized wood is oxidized into carbon dioxide, which removes oxygen from reactive mineral grains and ground water, and results in chemically reducing (oxygen-depleted) conditions during diagenesis. In the case of sulfate-bearing ground water, the reduction of sulfate produces sulfide ions, which react with iron to produce iron sulfides. This reaction goes on as long as there is carbon remaining in the sediments. In the Pikeview, Pulpit Rock, and Jimmy Camp Formation sandstone beds, iron sulfide appears to have nucleated on carbonaceous organic grains and grown outward into the sandstone pore space.

**Figure 13. Amalgamated cluster of small iron sulfide concretions weathering out of an outcrop of Pulpit Rock Formation (TKpr) along Cottonwood Creek in the Pikeview quadrangle; hammer head is about 7 inches long.**

**Figure 14. Fresh broken surface on a small iron sulfide concretion weathered out of the Pulpit Rock Formation (TKpr) along Cottonwood Creek in the Pikeview quadrangle; hammer head is about 7 inches long. In this view the sand grains and small quartz pebbles in a pebbly sandstone can be seen surrounded and cemented by iron sulfide.**

The diagenetic effects of carbon oxidation result in the concentration of iron, as sulfide, in certain sandstone beds, and as discrete iron-enriched layers within sandstone beds. As the iron-rich sandstone beds begin to oxidize, the unstable iron sulfide is converted into bright yellow- and orange-colored iron sulfate, which can be seen as an efflorescent crust on many outcrops along Cottonwood Creek. Further oxidation converts iron sulfate to iron oxide, which is very stable in the weathering environment (**figure 15**). The result is strong concentrations of iron oxides in some layers in the Dawson Formation and dense cementation of sandstone by iron oxides. These iron-oxide-cemented sandstone layers are more resistant to weathering and protect columns of more friable sandstone as pedestals and monument-like forms with flat, hat-like or mushroom-shaped tops that are characteristic of weathered Pikeview, Pulpit Rock, and Jimmy Camp Formation outcrops in the area, and locally called “hoodoos” (**figure 16**).

The Pulpit Rock member is generally permeable, well drained, and has good foundation characteristics. Excavation may be difficult, even though the arkoses are friable and easily eroded. The finer grained interbeds may be less stable and may have greater shrink-swell properties. The beds at the basal contact of the Pulpit Rock Formation may be particularly unstable when saturated with water. The block-failure of cliffs in the Pulpit Rock Formation poses a significant slope stability hazard in some residential areas.

### Jimmy Camp Formation, (TKjc) New Unit – Upper Cretaceous and Paleocene (TKda$_2$ on preliminary maps)

The Jimmy Camp Formation is composed of light-gray, greenish-gray, or brownish-gray pebbly or arkosic sandstone and minor pebble conglomerate interbedded with dark-gray to grayish-green, fine-grained micaceous sandstone and sandy claystone, and with dark-gray, greenish-gray and dark-brown sandy claystones with variable amounts of organic material. The unit is distinctive in weathered outcrops as the sandstone units weather to a greenish-gray to yellowish-gray “mustard” color (**figure 17**).

The sandstone beds of the Jimmy Camp Formation occur as thick to very thick beds that are poorly sorted, micaceous, and commonly massive or cross-bedded. The fine to very coarse sand-size grains are dominantly quartz with subordinate amounts of feldspar indicating that the source terrane probably contained considerable granitic or gneissic rocks. In many of the pebbly arkose beds, and pebble conglomerates, the pebbles include up to about 35% greenish-gray biotite, hornblende, or pyroxene andesite plus minor amounts light-gray biotite dacite (3.6%, see figure 10). The general yellowish-gray to yellowish-brown “mustard color” weathered appearance of these sands suggests that the matrix of the sandstones contains considerable clay material of probable montmorillonitic character and probably derived from the same volcanic source terrane as the andesitic

**Figure 15. Iron oxide halo around a fragment of carbonized wood (dark brown, friable material in the center of the iron oxide zone) in the uppermost pebble conglomerate bed of the Kpv unit on Cottonwood Creek (SE¼ SW¼ sec. 8, T. 13 S., R. 66 W.) in the Pikeview quadrangle. This style of iron oxide cements sandstone very densely into resistant layers that protect pedestals of more easily eroded sandstone below, and creates forms known locally as "hoodoos" (figure 16).**

**Figure 16. "Hoodoo" formation in the Pulpit Rock Formation (TKpr) in the Pikeview quadrangle.**

**Figure 17. Outcrops of the thick and very thick beds of pebbly sandstone and pebble conglomerate in the Jimmy Camp Formation (TKjc) along Jimmy Camp Creek, SE¼ sec. 3, T. 14 S., R. 65 W., in the Elsmere quadrangle. The beds in the foreground show the usual yellowish-gray weathering color of sandstone beds in this unit.**

pebbles. Varnes and Scott (1967, p. 16–17) recognized that the clays of an andesitic facies unit, now recognized to be the Jimmy Camp Formation of this work, were different from those of the arkosic facies. The clays in white and light-gray arkosic beds are characterized by kaolinite while the clays in yellowish-weathering greenish-gray andesitic beds are dominated by montmorillonite.

The sandstone and pebble conglomerate beds often contain petrified logs (**figure 18**), large fragments of coalified wood, and occasional tree stumps (**figure 19**). A series of stacked, sand-filled channel beds of Jimmy Camp Formation, well exposed at the top of the Corral Bluffs cliffs in the Corral Bluffs quadrangle from NE¼ sec. 1, T. 14 S., R. 65 W to SW¼ sec. 31, T. 13 S., R. 64 W., just beyond the east edge of the geologic map in Plate 1, contains hundreds of logs up to 4 feet in diameter and tens of feet in length. Similar beds with large accumulations of partially petrified logs can be found in exposures of the Jimmy Camp Formation in the NE¼ sec. 15, T. 13 S., R. 66 W., and in Rampart Park (NE¼ sec. 4, T. 13 S., R. 66 W.) Many of the sandstone and pebble conglomerate beds also contain large clasts (up to two feet in diameter) of claystone which have been eroded from the beds and banks of channels through which the sands were transported. The logs and claystone clasts indicate that the Jimmy Camp streams were very energetic and fast flowing. Measurement of the orientation of axes of trough cross-beds and the alignment of petrified logs indicates that most of the streams, which deposited the Jimmy Camp sands, were flowing towards the north.

The Jimmy Camp Formation contains occasional channels filled with thick beds of white to light-gray pebbly, cross-bedded arkose. These light-colored arkoses are the andesite-free arkose lithology of the Pulpit Rock Formation and appear to be the distal ends of channels of streams carrying light colored arkosic material from further to the west. The depositional patterns, and the interfingering of the lithologies of andesite-free and andesite-rich arkoses in the Jimmy Camp Formation can be explained by the westerly and southwesterly source of the light colored andesite free arkose (Pulpit Rock Fm), and a more southerly source of the mixed arkose and andesite plus dacite material in the Jimmy Camp Formation. Northerly directed paleocurrents from the Jimmy Camp Formation have been reported by (Benson, 1998; Robert Raynolds, personal communication, 2001) and confirmed in this work. **Figure 20** is a paleocurrent rose diagram of 73 measurements of cross bed channel axis directions from outcrops of the Jimmy Camp Formation in the Elsmere, Falcon NW, and Pikeview quadrangles. The average direction of current flow indicated by these measurements is 5 degrees (N05E). These measurements clearly indicate that the streams distributing the pebble conglomerate and pebbly sandstone of the Jimmy Camp Formation were flowing

**Figure 18. Mold and partial remains of a large petrified log about 35 ft long and 24 inches thick in the Jimmy Camp Formation from Rampart Park, NE¼ sec. 4, T. 13S., R. 66 W., in the Pikeview quadrangle. Hammer handle is 15 inches long.**

generally to the north, and spreading out into the basin as a north directed fan.

About 1000 feet of strata belonging to the Jimmy Camp Formation are exposed in the Elsmere quadrangle along Jimmy Camp Creek, starting near the Banning Lewis Ranch headquarters buildings (SE¼NE¼ sec. 9, T. 14 S., R. 65 W.) and continuing upstream into the Falcon NW quadrangle. This locality, and the outcrops along Jimmy Camp Creek, is designated as the type locality for the Jimmy Camp Formation. The Jimmy Camp Formation exposures extend to the northwest through the Falcon NW quadrangle, where the unit is well exposed along Sand Creek in a small neighborhood park in SE¼ sec. 19, T. 13 S., R. 65 W., and along Cottonwood Creek in secs. 1, 2, and 11, T. 13 S., R. 66 W.

The Jimmy Camp unit thins towards the northwest and is only about 400 feet thick in the north-central part of the Pikeview quadrangle. Beyond that location the lower part of the unit interfingers with the Pulpit Rock Formation and the upper part of the unit interfingers with or grades into

**Figure 19. Petrified remains of the stump and root structure of a palm tree buried upright, in growth position, in the Jimmy Camp Formation (TKjc); exposed beneath a sandstone ledge in a small tributary to Jimmy Camp Creek in NW¼ SW¼ sec. 3, T. 14 S., R. 65 W., in the Elsmere quadrangle. Hammer head is 7 inches long.**

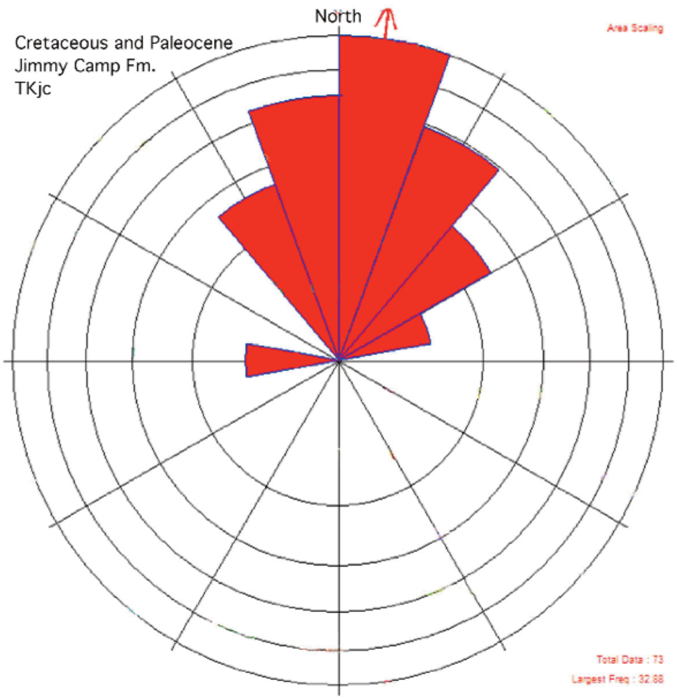



**Figure 20. Paleocurrent measurements for the Jimmy Camp Formation (TKjc) in the Elsmere, Falcon NW, and Pikeview quadrangles; measurements collected from 16 locations; number of measurements, 73; average direction (arrow) 5 degrees (N05E).**

the Black Squirrel Formation (Tbs) (figure 5). Good exposures of the unit Jimmy Camp Formation can be found in the Pikeview quadrangle in secs. 9 and 10, T. 13 S., R. 66 W. along Cottonwood Creek, and in Rampart Park in NE¼ sec. 4, T. 13 S., R. 66 W.

Considerable paleontological study of the Jimmy Camp Formation has been reported, mostly from the Jimmy Camp Creek drainage. Finlay (1916) reported the discoveries of fossil leaves and vertebrates from the area, apparently in part from the Jimmy Camp unit. Benson (1998) documents several large collections of Cretaceous and Paleocene fossil leaves from sites along Jimmy Camp Creek. Johnson and Raynolds (2001) have collected fossil bones from a crocodilian in adjacent Corral Bluffs quadrangle, and nearby areas have produced jaws of Paleocene mammals (Eberle, 2003), from the Jimmy Camp Formation.

Three fossil leaf collections reported in Benson (1998) and a fourth site described by Kirk Johnson (Curator of Paleontology, Denver Museum of Nature and Science, personal communication, 2001), constrain the K-T boundary to somewhere within about 100 feet of section. At the sites named Lyco-Luck (DMNH-2124) and Kristianity (DMNH-2174) large collections of leaves are clearly late Cretaceous in age. Higher up in the section collections from Rainmagnet (DMNH-2131) and Bambi Meets McPhee (Benson location 9766) locations are early Paleocene. Sampling and identification of palynomorphs by Farley Fleming (quoted in Benson, 1998, p. 123) along Jimmy Camp Creek confirm the restriction of the K-T boundary to within about 100 feet of stratigraphy. Progress in this work has been reported by Ian Miller (DMNS, personal commun., 2007) who has approximately located the K-T boundary also in the Jimmy Camp Formation on Cottonwood Creek, about 1000 feet west of the Ravenswood Drive bridge, in SW¼ sec. 10, T. 13 S., R. 66 W., in the Pikeview quadrangle.

In the present work, fragments of probable dinosaur bone were found in yellow-brown sandstones of the Jimmy Camp Formation a short distance below the late Cretaceous fossil leaf sites that constrain the Cretaceous/Tertiary boundary. Higher up in the section (well above the KT boundary) a fossil bone from a possible large turtle was found in very coarse pebbly arkose of the Jimmy Camp Formation in NE¼ sec. 3. T. 14 S., R. 65 W.

Clastic dikes were found in outcrops of the Jimmy Camp Formation in the bed of Cottonwood Creek. In low outcrops along the north side of the stream about 500 feet downstream from the north end of Gambol Quail Drive (SE¼SW¼ sec. 9, T. 13 S., R. 66 W.) a swarm of northwest-trending, light-gray sandstone clastic dikes, 3 to 6 inches thick, cut dark-green sandy claystones. A coalified tree stump was found nearby, buried upright in growth position. A second swarm of clastic dikes were found about 1500 feet west of the Union Boulevard bridge over Cottonwood Creek in NW¼SE¼ sec. 9, T. 13 S., R. 66 W. Here several clastic dikes originated in a gray coarse sandstone bed, penetrate upwards through a dark-grayish-brown sandy claystone bed about 4 ft thick, and connect with an overlying lenticular bed of gray sandstone. The upper sandstone bed appeared to be a “sand volcano” or “sand blow.” The sand deposited as the upper sandstone bed appears to have originated from the lower sandstone bed and may have been transported upward to the surface as a fluidized slurry. Unfortunately, flood control efforts, which required the rebuilding of a small dam on Cottonwood Creek, have buried the sand volcano outcrops.

The orientation of the clastic dikes in the above sand volcano occurrence varies from N20°W to N55°W, and they dip steeply towards the southwest. The gray clastic dikes are contorted by the compaction of the dark-grayish-brown sandy claystone bed, indicating that the sandy claystone was uncompacted and plastic during the emplacement of the clastic dikes. Dewatering and compaction of the sandy claystone distorted the gray sands of the clastic dikes, which contained less water and were less compactible. The dip of the clastic dikes may have been caused by creep of unconsolidated sediments basinward, towards the northeast, rotating the sand dikes into the steep southwest dip. The northwest trend of clastic dikes in the Jimmy Camp Formation, at the above locations, is markedly different from the northeasterly trends of similar clastic dikes in the Pikeview Formation.

One paleosol bed was found in an outcrop of Jimmy Camp Formation along Pine Creek, just east of Highway 83 in SE¼NE¼, sec. 32, T. 12 S., R. 66 W. This paleosol, in the westernmost part of the unit, and the numerous paleosols in the upper part of the Pulpit Rock Formation along Monument Creek, suggest an explanation for the transport of mixed andesitic-granitic material into the basin, from the south, during the deposition of the Jimmy Camp Formation. The Pikeview Formation (Kpv) is dominated by andesitic material, but the Pulpit Rock Formation is essentially andesite-free. The paleosol beds in the Pulpit Rock and western-most Jimmy Camp Formations were formed during small periods of uplift, erosion, and oxidation along the mountain front. Numerous paleosol beds in the upper part of Pulpit Rock Formation indicate that uplift and erosion closer to the mountain front was episodic and repeated. This uplift and erosion suggests that reintroduction of andesite debris into the basin in the Jimmy Camp Formation, mixed with arkosic material, may have been in part the result of erosion of the Pikeview Formation. Much as the Pierre Shale and Fox Hills Sandstone were being eroded and truncated during the deposition of the Pikeview Formation, some of the Pikeview Formation may have been eroded and truncated during the deposition of the Jimmy Camp Formation. However, some of the andesitic material, and the biotite dacite pebbles, in the Jimmy Camp unit represent the introduction of new volcanic material into the basin. Much of the andesitic material in the Jimmy Camp Formation has both different petrology and different chemistry than the andesites of the Pikeview Formation. For additional information on the petrography, and chemistry of the volcanic pebbles in the Jimmy Camp Formation, see a later section of this report.

Figure 10 shows the percentages of various pebble lithologies in the Jimmy Camp Formation. Although this unit has significant andesite pebbles (36%) the data support the conclusion that the unit was derived from a mixed source terrane that had more granite (19.7% granite pebbles plus 39% feldspar and quartz pebbles probably derived from weathering granite) than andesite. The introduction of a small but significant amount of biotite dacite pebbles reinforces the interpretation that the source terrane for the Jimmy Camp Formation volcanic pebbles was different that those in the Pikeview Formation. Further analysis of the differences between the volcanics in these two units is described in a following section on the petrology and chemistry of the volcanic pebbles in the Denver Basin.

The sandstones and arkoses of the Jimmy Camp Formation are generally stable and have good foundation characteristics. The finer grained, more clay-rich lithologies are less stable and should be expected to have high shrink-swell properties.

### Black Squirrel Formation (Tbs) New Unit - Paleocene (TKda$_3$ on preliminary maps)

The Black Squirrel Formation in the Colorado Springs area consists of sub-equal amounts of three lithologies: (1) thick and very thick-bedded, massive and cross-bedded, white, tan, and light-gray arkose and pebbly arkose; (2) thin to thick beds of light-green to olive-gray, clay-rich, fine- to medium-grained micaceous and feldspathic sandstone; and (3) thin to thick beds of dark-gray to greenish-gray sandy claystone. In the Monument quadrangle the unit is 500 to 600 feet thick. It thins towards the northwest as it inter-fingers with the Pulpit Rock Formation and probably with the overlying Dawson Arkose (Tda). The unit is also gradational and inter-fingering with the underlying Jimmy Camp Formation where that unit lies below the Black Squirrel Formation (figure 5). The amount of sandstone in the Black Squirrel Formation appears to increase towards the west, towards the paleo-mountain front, as the unit inter-fingers with the Pulpit Rock Formation and the Dawson Arkose. This gradational relationship makes a zone of mapping uncertainty where the contact may be rather arbitrary.

The very thick-bedded, massive or cross-bedded, light-colored arkose beds in Black Squirrel Formation resemble those in the Pulpit Rock unit but are finer grained and generally thinner. Most of the grains in these arkoses are less than 1/2 inch in diameter; a few pebbles are up to 1 1/2 inches. The lithologies of the coarse grains are much more varied than those in the arkoses of the Pulpit Rock Formation, with grains of quartz, white feldspar, pink feldspar, white granite, pink granite, and small amounts of tan vuggy dolomite and red, black, or orange-brown chert. A few sub-round to round pebbles of altered volcanic rocks occur, but these are the least common of all the clast lithologies.

The light-green to olive-gray, clay-rich, fine- to medium-grained micaceous and feldspathic sandstone and the dark-gray to greenish-gray sandy claystone resemble lithologies in the lower part of the Jimmy Camp Formation in the Pikeview and Elsmere quadrangles (Thorson and others, 2001; Madole and Thorson, 2002). The finer-grained lithologies in the Black Squirrel Formation are characterized by greenish colors, suggestive that the facies contains considerable montmorillonitic clay (Varnes and Scott, 1967). In exposures of the Black Squirrel Formation in the bed of Monument Creek downstream from Baptist Road (sec. 35, T. 12 S., R. 67 W.) the finer-grained beds of this facies also contain thin, poorly developed paleosols.

The Black Squirrel Formation is well exposed in the bed and banks of Black Squirrel Creek and Kettle Creek in the southeastern corner of the Monument quadrangle. The outcrops of this unit along Black Squirrel Creek, above and below the bridge over the creek on Highway 83 (sec. 16, T. 12 S., R. 66 W.) are designated as the type locality of the Black Squirrel Formation. Exposures of this unit in the banks of Kettle Creek (sec. 13, 14, 15, 16 and 21, T. 12 S., R. 66 W.) are a useful additional section that illustrates the variability of the Black Squirrel Formation lithologies. The Hopi Oil well (NW¼ SW¼ sec. 31, T. 11 S., R. 66 W.) encountered coaly intervals in strata that have been assigned this formation, although the coaly beds do not crop out at the surface.

The map symbol for the Black Squirrel Formation, "Tbs", used in this work, reflects that the unit is, as far as is known, Paleocene in age. This age for the Black Squirrel Formation in the Colorado Springs area is based on paleontological criteria. The Denver Museum of Nature & Science made a fossil leaf collection from a site in the lower part of the Black Squirrel Formation that K.R. Johnson considers to be Paleocene (Baptist Road, DMNH 2177, personal commun, 2007). Recently a fossil pollen sample from a collection site in the SE¼ sec. 25, T. 11 S., R. 67 W. (sample JPT-07-M-02, DBP-2007-89) yielded a palynological age of early mid-Paleocene pollen zone P3 (D.J. Nichols, written commun., 2007). Another pollen sample (JPT-07-M-01, DBP-2007-88) collected from a road cut along Baptist Road (SW¼SW¼ sec. 29, T. 11 S., R. 66 W.) in the Dawson Arkose (Tda), stratigraphically above the early mid-Paleocene pollen, returned an assignment to late mid-Paleocene pollen zone P4 (D.J. Nichols, written commun., 2007). Therefore, the deposition of the Dawson Arkose (Tda), overlying the Black Squirrel Formation in the Monument quadrangle, began in the late middle Paleocene, and thus, the age of the top of the Black Squirrel Formation at this locality is no younger than mid-Paleocene.

The new pollen collection from the Black Squirrel Formation came from a sample of brown organic-rich fine sandstone and siltstone that was collected from the cut slope behind the shopping center buildings on the north side of Baptist Road (**figure 21**) in SW¼SE¼ sec. 25, T. 11 S., R. 67 W. (513755E 4323022N, UTM m, zone 13, NAD 27, sample JPT-07-M-02, DBP-2007-89). D.J. Nichols, Research Associate, Denver Museum of Nature & Science, reported in a written communication, October 23, 2007,

"DBP-2007-89 JPT-07-M-02

The sample yielded mostly cutinite but also a fairly diverse assemblage of palynomorphs. Species characteristic of palynostratigraphic Zone P3 indicate an age of early middle Paleocene. Species present include:

*Cupanieidites inaequalis*

*Cyathidites diaphana*

*Laevigatosporites sp.*

*Lanagiopollis lihokus*

*Momipites anellus (relatively abundant)*

*Momipites waltmanensis*

*"Paliurus" triplicatus*

*Psilastephanocolpites sp.*

*Retitrescolpites anguloluminosus*

*Taxodiaceaepollenites hiatus*

*Tilia vescipites"*

The sandstones and arkoses of the Black Squirrel Formation are generally stable and should have good foundation characteristics. The finer-grained, more clay-rich, lithologies should be expected to be less stable and may have high shrink-swell potential.

**Figure 21. Sample site for pollen sample JPT-07-M-02 (DBP-2007-89); site has been modified since the sample was collected in 2007, but the brown, fine sandstone and siltstone beds containing the P3 zone pollen are exposed in the fresh cut slope above and to the right of the truck.**

### Dawson Arkose (Tda) - Paleocene to Eocene ($TKda_4$ and $Tkda_5$ on preliminary maps)

The Dawson Arkose is similar to the Pulpit Rock Formation. The unit is dominated by very thick bedded to massive, cross-bedded, light-colored arkoses, pebbly arkoses, and arkosic pebble conglomerate, and contains numerous 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. The unit also contains massive structureless beds that are interpreted as mudflows; these beds occasionally have dark-colored tops, which are organic-rich soil zones. The Dawson Arkose contains only rare interbeds of thin- to very thin-bedded gray claystone and sandy claystone, or dark-brown to brownish-gray, organic-rich siltstone to coarse sandstone containing plant fragments.

The arkose and sandstone beds of the Dawson Arkose are light colored largely due to diagenetic alteration of the feldspars to clay, mostly kaolinite. The intensity of bleaching and alteration of feldspar grains in this unit is very strong near the base, but decreases upward. Near the top of the unit many of the feldspar grains are still pink perthitic feldspar similar to that in the presumed source rock for this unit, the Pikes Peak Granite. The Dawson Arkose is estimated to be 800 to 1000 ft thick in the section from the Monument quadrangle eastward to the top of the formation in the Black Forest quadrangle. The top of the unit has been removed by an Eocene erosional event in all the sections where an upper contact is observed. The unit is overlain by the Larkspur Conglomerate, the Wall Mountain Tuff, or the Castle Rock Conglomerate in exposures extending from the northern part of the Black Forest quadrangle, northward to the Highlands Ranch and Parker quadrangles.

In preliminary maps south of Palmer Divide the Dawson Arkose was separated into two map units, $TKda_4$ and $TKda_5$, separated by a paleosol zone. This paleosol was found in several places in the Monument quadrangle and was postulated to be the regional paleosol traced around the Denver Basin by Soister and Tschudy (1978), which has been used as a *de facto* marker for the Paleocene - Eocene boundary, and for the D1 - D2 boundary (Raynolds, 1997, 2002).

The paleosol in the Monument quadrangle is a recessive unit and appears to be discontinuous, but several man-made exposures allow it to be followed generally across the quadrangle. Near the town of Monument, a stratigraphic interval containing multiple paleosols was exposed in road cuts and road-side ditches on Beacon Lite Road in the NE ¼ SE ¼, sec. 10, T. 11 S., R. 67 W. Here bright-maroon to dark-red, very clayey, coarse sandstone and fine-pebble conglomerate are interbedded with very coarse light-gray to pink pebbly arkose and pebble conglomerate in a sequence of strata about 40 ft thick. The reddish-colored zones are often mottled with yellow-brown and greenish-gray patches, and are cut by root structures. These reddish-colored zones are very clayey and have very coarse sand-size grains or fine pebbles of clear and light- to dark-gray quartz in a matrix of red, maroon, yellow-brown, or greenish-gray sandy claystone. The quartz grains are generally matrix supported. This paleosol horizon can be followed intermittently west from the Beacon Lite Road exposure into the Palmer Lake quadrangle. Another exposure of paleosol, correlated with the paleosol exposed along Beacon Lite Road, is exposed on the east shore of Lake Woodmoor (NW¼ NE¼, sec. 14, T. 11 S., R. 67 W.).
A third exposure of a paleosol correlated with the Beacon Lite paleosol crops out at the corner of Lake Woodmoor Drive and Highway 105 (C. sec. 13, T. 11 S., R. 67 W.).

A similar paleosol was exposed in the excavation for a residence at the corner of Brenthaven Court and Colonial Park Drive (just off Higby Road, SW¼ NW¼, sec. 20, T. 11 S., R. 66 W.) early in June, 2001. At the time this area was mapped (2001) about 10 ft of mottled red-orange and olive-green to yellow-green clay-rich arkose and sandy claystone was exposed. This paleosol was found to contain well preserved root structures and a filled burrow about 1 inch in diameter. Part of this paleosol is still exposed in a road-side ditch along Brenthaven Court. Another exposure of the Brenthaven horizon occurs in the road-side ditch along Dolan Drive about 2,000 feet further to the southeast. Another well-developed paleosol exposure, about 30 ft thick, is exposed in a road cut on Highway 83 about 300 ft south of the intersection with Stage Coach Road (SW¼ NE¼, sec. 34, T. 11 S., R. 67 W.).

For the present work, the use of the paleosol as a mapping boundary was discontinued and units $TKda_4$ and $TKda_5$ were lumped together as the Dawson Arkose. This decision was made for several reasons:

A. The Dawson Arkose map unit (Tda) is based on its lithologic characteristics; the unit is dominated by thick to very thick, massive or cross-bedded light colored arkose and sandstone.

B. The paleosol is a recessive unit, and can not be followed consistently, particularly in natural exposures. There are many locations where there is no evidence for a paleosol zone at a location where the zone might be projected from other exposures.

C. If the paleosol is used as a mapping boundary, it occurs between two virtually identical map units ($TKda_4$ and $TKda_5$) that can only be separated arbitrarily by projecting the location of the intermittent paleosol zone.

D. In the area considered in this report, it has been established in many places that there are multiple paleosol zones in the Denver Basin Paleocene strata (Pikeview quadrangle, Thorson and others, 2000; Monument quadrangle, Thorson and Madole, 2003; Black Forest quadrangle, Thorson, 2003; Palmer Lake quadrangle, Keller and others, 2006; Larkspur quadrangle, Thorson and others, 2008; and Dawson Butte quadrangle, Morgan and others, 2004). No individual paleosol exposure can be confirmed to be the zone proposed by Soister and Tschudy (1978) as the boundary between the Paleocene and Eocene strata in the Denver Basin without paleontological confirmation.

E. The Dawson Arkose is a map unit of consistent lithologic character that can be traced from the Falcon NW quadrangle to the Highlands Ranch quadrangle, a distance of about 40 miles. In the area of the geologic map in Plate 1 and 2, this unit is consistently the uppermost synorogenic unit of the Denver Basin.

F. There are unresolved problems with the Paleocene stratigraphy of the Denver Basin. The utility of Soister and Tschudy's regional paleosol zone as the boundary between mid-Paleocene (pollen zone P3 strata) and Eocene strata has been supported by Nichols and Fleming, 2002, Raynolds, 2002, Raynolds and Johnson, 2003, and Nichols, 2003, all of whom have embraced the concept of a late-Paleocene unconformity and hiatus of about 8 million years. These authors all support the occurrence of very thin late-P6 pollen zone strata below the Soister and Tschudy (1978) paleosol. All of these authors have anticipated that strata spanning the pollen zones from early-P3 zone to mid-P6 zone are missing from the Denver Basin. Recent palynological work done for this compilation of CGS mapping has established the occurrence of previously unreported pollen from zones P4 and P5 in the Denver Basin.

A new pollen collection is here reported from the Dawson Arkose in the Monument quadrangle. A sample of dark brown, lumpy, coarse- to very coarse-grained arkosic sandstone with an organic-rich matrix, from about 2 to 3 feet above a prominent dark brown to black swampy soil zone in a road cut on Baptist Road, was collected and submitted to D.J. Nichols (Research Associate, Denver Museum of Nature & Science) for preparation, identification and interpretation of pollen species. The sample came from the location pictured in **figure 22**, located in SW cor. sec. 29, T. 11 S., R. 66 W. (516322E 4322864N, UTM m, zone 13, NAD 27, sample JPT-07-M-01, DBP-2007-88). D.J. Nichols reported in a written communication, October 23, 2007,

"DBP-2007-88 JPT-07-M-01

There was poor recovery from the sample, which yielded only a few palynomorphs. Despite the poor recovery, presence of species characteristic of palynostratigraphic Zone P4 and absence of Zone P5 species indicate an age of late middle Paleocene. Species present include:

*Cyathidites minor*

*Laevigatosporites sp.*

*Momipites anellus (relatively abundant)*

*Momipites wyomingensis*

*Retitrescolpites anguloluminosus*

*Pityosporites sp.*

*Taxodiaceaepollenites hiatus"*

Thus, there are late middle Paleocene strata in the Denver Basin deposited during a time previously thought to be characterized by either erosion or non-deposition. And further, the utility of the paleosol, identified by Soister and Tschudy (1978) and widely used as a regional marker for the Paleocene - Eocene boundary, is here strongly questioned.

The sandstones and arkoses of the Dawson Arkose are generally stable and should have good foundation characteristics. The finer-grained, more clay-rich lithologies should be expected to be less stable and may have high shrink-swell potential. Occasionally, parts of the Dawson Arkose are well cemented and stand out as cliffy outcrops that may be rock fall and block failure hazards to structures or improvements built below.

## CASTLE ROCK AREA

It was not possible to extend most of the subdivisions of the Denver Basin Group applicable in the Colorado Springs area, described earlier in this report, north beyond the Palmer Divide in the north part of the Palmer Lake and Monument quadrangles. However, the uppermost unit of the Dawson Formation, the Dawson Arkose (Tda), is mappable continuously from the Falcon NW quadrangle to the Highlands Ranch quadrangle. It was also not possible to extend the very complicated stratigraphic subdivisions used by Maberry and Lindvall (1972, 1977) in the Parker and Highlands Ranch quadrangles. All of the lithologies below their upper units of arkosic sandstone are included within the Denver Formation in this work. Therefore, the map unit that has previously been shown as the upper part of the Dawson Formation (Trimble and Machette (1979a) and as Dawson Arkose by Bryant and others (1981) is here subdivided and mapped as two formations; the Denver Formation overlain by an uppermost arkosic sandstone unit, the Dawson Arkose. This use of the Dawson Arkose restricts the formation name to the uppermost 100 to perhaps 400 feet of strata in the Castle Rock area.

The problem of how the stratigraphy of the Colorado Springs area is related to that of the Denver area is complicated and has been an unresolved problem to both groups of previous authors who have considered a solution; Trimble and Machette (1979a, 1979b), and Bryant and others (1981). Raynolds (1997, 2002, 2003) started a promising revision of the stratigraphy of the Denver Basin when he defined two synorogenic sequences, D1 and D2. That revision has been carried further to redefine the synorogenic Cretaceous through early Eocene strata of the Denver Basin, previously called by many names, as the Denver Basin Group (Figure 4). In the Castle Rock area two formations have been mapped, Denver Formation and Dawson Arkose, as subdivisions of the Denver Basin Group (see figure 4). The Arapahoe For-

**Figure 22. Road cut near the base of the Dawson Arkose from which sample JPT-07-M-01, (DBP-2007-88) was collected for palynological (pollen) identification. The sample was collected from brownish-gray clayey sandstone in the upper part of the darker zone at the top of the outcrop. The palynological age reported for these strata is Paleocene pollen zone P4.**

mation, the lowest formation in the Denver Basin Group is not exposed in the map area of Plate 1, but is projected to be present in the subsurface, see Plate 3.

### Denver Formation (TKd) - Upper Cretaceous and Paleocene(TKda$_4$ on preliminary maps)

Strata mapped as the Denver Formation in the Castle Rock area are lithologically quite variable and similar to the lithologies described by Maberry and Lindvall (1972, 1977) at the southern edge of the Denver metropolitan area. Unfortunately, the exposures in the Castle Rock area are not complete enough to carry the detailed map units used by Maberry and Lindvall, however many of the same lithologies are recognizable. The Denver Formation is a mixture of greenish-gray to light-gray sandy claystone and clayey sandstone and beds of white to light-tan, fine- to medium-grained, feldspathic cross-bedded friable sandstone similar to those in the overlying 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. About 400 to 500 feet of the Denver Formation is exposed in the Castle Rock area, but its base is not exposed.

The map symbol "TKd, Tertiary-Cretaceous Denver Fm." has been used for the Denver Formation, in the Castle Rock area, because parts of the Denver Formation in the Denver area are known to be Cretaceous (Brown, 1943). Until the K-T boundary has been traced through the western edge of the basin, it must be assumed that the Denver Formation in the Castle Rock area might also contain Cretaceous strata.

A common and distinctive lithology of the Denver Formation is olive green sandy claystone that appears to be derived from the weathering of andesitic debris. In a few locations these andesitic beds have remnants of pebbles confirming that they were andesitic pebble conglomerate or pebbly sandstone containing andesite pebbles. In one outcrop along Highway I-25 in the Parker quadrangle (SE¼ sec. 22, T. 6 S., R. 67 W.) andesite pebbles were found to be atypically well preserved. Andesite pebbles from this sample, collected near a Denver Museum of Nature & Science fossil leaf site called Climbing Lane (Beth Ellis, personal commun., 2007) were yellow gray to light red-brown andesite with abundant small blocky plagioclase phenocrysts altered to white clay, and in the matrix, small phenocrysts of altered green pyroxene and black illmenite or magnetite. Minor amounts of other andesite lithologies, similar to those found in the Denver Formation in the Morrison quadrangle farther to the northwest, were found in this pebble conglomerate.

The amount of light colored sandstone in the Denver Formation in the Castle Rock area varies considerably. Closer to the mountain front in the Sedalia, Dawson Butte, and Larkspur quadrangles, the amount of sandstone in the Denver Formation makes it difficult, and sometimes arbitrary, in mapping a contact between the Dawson Arkose and the underlying Denver Formation. The overlying Dawson Arkose is more coarse grained, has thicker bedding in the sandstones, and much less interbedded greenish-gray sandy claystone. In studies of the subsurface geology of the Denver Formation and underlying Arapahoe Formation (or the D1 unit of Raynolds), using mostly water well logs, Peter Barkmann and Bob Raynolds (personal commun, 2007, Barkmann and others, in press) can demonstrate parts of this unit that contain higher amounts of sandstone beds apparently deposited by fluvial fan systems coming off of the mountain front. They have adopted the name "Wildcat Fan" for this sandstone unit that outcrops west of the area of Plate 1. The Wildcat Fan unit is not shown on Plate 1 since it does not outcrop in the map area, but is shown on the accompanying cross sections (Plate 3) where it has been recognized in the subsurface.

In places the top of the Denver Formation is marked by the 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 (2001) Farnham and Kraus (2002) and Nichols and Fleming, (2002), and 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 in the northeast part of the Castle Rock North quadrangle in two clay pits (NW¼ sec. 35, T. 6 S., R. 66 W. and NE¼ sec. 8, T. 7 S., R. 66 W.) and in Newlin Gulch (SW¼ sec. 30, T. 6 S., R. 66 W.). Other excellent exposures of this paleosol were found in construction excavations in the northeastern part of the Castle rock North quadrangle during fieldwork but have proved to be ephemeral, being buried as frequently as they were exposed. In the northeast part of the Castle Rock North quadrangle, and westward through the Parker and Highlands Ranch quadrangles where the paleosol was mapped as "variegated mudstone" by Maberry and Lindvall (1972, 1977), the Denver Basin paleosol marks the boundary between the Denver Formation and the overlying Dawson Arkose. The top of the Denver Formation as used in this report, and as used by Maberry and Lindvall (1972, 1977), appears to correlate with the top of Raynolds' (2002) D1 sequence, but does not correlate specifically with any of the units used by Bryant, 1981).

South from the Highlands Ranch quadrangle to Palmer Lake, a paleosol that might be the Denver Basin paleosol is only sporadically exposed. The projected location of this paleosol should be just above the Castle Rock rainforest leaf fossil locality (Ellis and others, 2003, Johnson and others, 2003) of mid-Paleocene age. A cluster of paleosol locations have been mapped in the area between Dawson Butte and Larkspur; two of these occurrences have been widely regarded as exposures of the Denver Basin paleosol, on the west side of Dawson Butte (west edge sec. 6, T. 9 S., R. 67 W., and Hunt Mountain (NE¼ sec. 22, T. 9 S., R. 67 W.

In this case 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 any paleosol occurrence as a distinctive time marker.

The Denver Formation is quite variable in permeability but usually well drained at the surface. 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 has become common practice in subdivision construction in the southern Denver metropolitan area to excavate areas of clay-rich Denver Formation from areas of 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 Denver Formation.

### Dawson Arkose (Tda) - Paleocene to Eocene (Tkda$_5$ and TKda$_6$ on preliminary maps)

The uppermost unit of the Denver Basin stratigraphy in the Castle Rock area is the Dawson Arkose, which can be traced continuously from the Falcon NW quadrangle to the Highlands Ranch quadrangle. The Dawson Arkose is dominated by very thick-bedded to massive, cross-bedded, light-colored arkoses, pebbly arkoses, and arkosic pebble conglomerate, but also 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.

In the northeastern part of the map area, occasional light green, olive-green or brown sandy claystone occur interbedded with the coarser units. The greenish sandy claystones resemble those in the Denver Formation and emphasize the gradational, and probably inter-fingering, relationship between the Dawson Arkose and underlying Denver Formation. The contact between these two units was placed at the paleosol exposure in the Robinson Brick clay pit (NW¼ NW¼ sec. 35, T. 6 S., R. 66 W., Castle Rock North quadrangle), long suspected to be the regional paleosol of Soister and Tschudy (1978). In the context of recent pollen ages of the upper part of the section from the northeastern part of the map area (reviewed below), particularly in the drainage of Cherry Creek, and in road-side outcrops along Highway 83 in the Castle Rock North and Russellville Gulch quadrangles, the contact between the Denver Formation and Dawson Arkose may need to be re-evaluated.

Occasionally the Dawson Arkose 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 that indicate their origin as paleosols;

others are probably just the result of oxidation by groundwater. The Dawson Arkose is about 800 feet thick in the area of the Palmer Divide but thins northwards so that the unit is 150 to 200 feet thick in the Parker to Highlands Ranch area. The upper part of the Dawson Arkose generally forms steep cliffs at the top of the section; in some locations because the unit is protected by more resistant overlying units like the Wall Mountain Tuff or Castle Rock Conglomerate, in others simply because the top of the Dawson Arkose is more firmly cemented (**figure 23**). The basal contact is commonly not well exposed, and the top of the unit has been removed by erosion.

Locally, particularly on the Cherry Valley School and Larkspur quadrangles, a distinctive facies occurs at the top of the Dawson Arkose. This facies looks in most respects similar to the thick bedded and cross bedded arkose and pebbly arkosic sandstone of the Dawson Arkose, except for more common, sub-angular to sub-round large pebbles and occasional small cobbles of white quartz. The unit's distinct characteristics are the white quartz clasts, coarser clast size, and more conglomeratic aspect than the underlying part of the Dawson Arkose. The unit was deposited in indistinct channels cut into the top of the underlying part of the Dawson Arkose. The unit appears to represent a facies that was deposited in response to uplift of the basin margin (probably at the western, mountain-front, edge) by erosion and reworking of some of the older Dawson Arkose. Such an origin could explain the greater concentration and larger clasts of white quartz, which would have been more resistant to weathering and erosion, and therefore concentrated as pebbles when conglomeratic or pebbly arkose was eroded and redeposited. This facies unit (TKda$_6$) was mapped individually on the preliminary maps of the Cherry Valley School and Larkspur quadrangles (Thorson, 2004; Thorson and others, 2008), but for the purposes of this report was combined with the rest of the Dawson Arkose. In recent work Peter Barkmann and Matt Morgan (2010, personal commun.) have reported that this facies unit occurs widely at the top of the Dawson Arkose in the Elizabeth and Elbert quadrangles, just east of the map area in Plate 1.

Four recent palynological collections are relevant to the age of the Dawson Arkose in the Castle Rock area. The first is sample G-101 collected from a road cut along Interstate Highway 25 between the Greenland and Larkspur exits (**figure 24**), and just south of the rest area on the northbound lanes between these exits (NW¼NE¼ sec. 3, T. 10 S. R. 67 W., Greenland quadrangle; 510896E 4340446N UTM m, zone 13, NAD 27, sample JPT G-101, DBP-2007-87). D.J. Nichols, Research Associate, Denver Museum of Nature & Science, reported in a written communication, October 23, 2007;

"JPT G-101 DBP-2007-87

There was good recovery from the sample, which yielded a diverse assemblage of palynomorphs. An age of late middle Paleocene is indicated by presence of species characteristic of palyno-stratigraphic Zone P4 and absence of Zone P5 species. Species present include:

*Alnus speciipites*

*Chenopodipollis sp.*

*Laevigatosporites sp.*

**Figure 23. Exposures of Dawson Arkose on the south side of Spruce Mountain (SW¼ sec. 22, T. 10 S., R. 67 W.) in the Larkspur quadrangle. This exposure shows thickly bedded strata and characteristic steep cliffy exposure of the top of the unit with lower slopes covered with coluvium and sheetwash; beneath those surficial units is the projected contact with the Denver Formation. The flat-topped buttes on the skyline are, from right to left, Corner Mountain, Rattlesnake Butte, and Nemrick Butte capped with Wall Mountain Tuff and Larkspur Conglomerate.**


**Figure 24. Dawson Arkose in a road cut along Interstate Highway 25 (NW¼NE¼ sec. 3, T. 10 S. R. 67 W., Greenland quadrangle) from which a Paleocene P4 pollen zone age was reported; sample G-101 was collected from the beds of brown fine sandstone and siltstone that are exposed above and to the right of the truck.**

*Momipites anellus*

*Momipites ventifluminis*

*Momipites wyomingensis*

*Triatriopollenites granilabratus*

*Triatriopollenites subtriangulus*

*Ulmipollenites krempii"*

Two samples were collected from roadside outcrops along Parker Road, near the intersection with Scott Road, about 4.5 miles south of the town of Parker (**figure 25**). Sample JPT07-CRN-01 was collected from outcrops mapped as Dawson Arkose in SE¼SE¼ sec. 10, T. 7 S., R. 66 W.; 520719E 4366568N UTM m, zone 13, NAD 27, DBP-2007-77. Sample JPT07-CRN-02 (DBP-2007-78) was collected from the same outcrop about 20 m (70 feet) further south at 520719E 4366548N UTM m, zone 13, NAD 27.

D.J. Nichols, Research Associate, Denver Museum of Nature & Science, reported about these two samples in a written communication, October 23, 2007;

"JPT-07-CRN-01 DBP-2007-77

There was good recovery from the sample, which yielded a diverse assemblage of palynomorphs. Late (but not latest) Paleocene age is indicated by presence of species characteristic of palynostratigraphic Zone P5 (Nichols, 2003). Species present include:

*Alnus speciipites*

*Bombacacipites sp. (cf.)*

*Caryapollenites inelegans*

*Caryapollenites veripites*

*Caryapollenites wodehousei*

*Laevigatosporites ovatus*

*Momipites ventifluminis*

*Momipites wyomingensis*

*Pityosporites sp.*

*Polyatriopollenites vermontensis*

*Rhoipites sp.*

*Taxodiaceaepollenites hiatus*

*Triatriopollenites subtriangulus*

*Tricolpites hians*

JPT-07-CRN-02 DBP-2007-78

There was fair recovery from the sample, which yielded a fairly diverse assemblage of palynomorphs. Late (but not latest) Paleocene age is indicated by presence of species characteristic of palynostratigraphic Zone P5 (Nichols, 2003). Species present include:

*Bombacacipites sp. (cf.)*

*Caryapollenites imparalis*

**Figure 25. Outcrops of brown organic-rich fine sandstone and coaly sandstone exposed on the west side of Parker Road (SE¼SE¼ sec. 10, T. 7 S., R. 66 W., Castle Rock North quadrangle). These strata were mapped as an interbed between arkose beds of the Dawson Arkose; samples CRN-01 and CRN-02 were collected from this exposure.**

*Caryapollenites inelegans*

*Caryapollenites veripites*

*Caryapollenites wodehousei*

*Chenopodipollis sp.*

*Cyathidites minor*

*Laevigatosporites ovatus*

*Momipites ventifluminis*

*Momipites wyomingensis*

*Pityosporites sp.*

*Polyatriopollenites vermontensis*

*Taxodiaceaepollenites hiatus*

*Triatriopollenites subtriangulus"*

The three pollen samples described above were collected from near the base of the Dawson Arkose, probably within 100 ft from the top of the Denver Formation. Outcrops of a paleosol attributed to be the Denver Basin paleosol of Soister and Tschudy (1978) occur about 2 miles north of each of these locations. These pollen assemblages indicate that the deposition of the Dawson Arkose began in the late middle Paleocene to late Paleocene and that there is no significant hiatus between pollen zones P3 and late P6 at these locations. Raynolds, 2002; Raynolds and Johnson, 2003, and Nichols, 2003, have all attributed much significance to the supposition that no pollen from zones P4, P5, and most of zone P6 occur in the Denver Basin.

A fourth pollen collection, from an artificial cut near the top of the Dawson Arkose in NE¼SE¼ sec. 24, T. 8 S., R. 67 W., (sample JPT-CRS-04, DBP-2007-85, 514500E 4354250N UTM m, zone 13, NAD 27, now re-contoured and covered with soil, **figure 26**), yielded a latest Paleocene assemblage. D.J. Nichols, Research Associate, Denver Museum of Nature & Science, reported in a written communication, October 23, 2007;

"JPT-CRS-04DBP-2007-85

The sample yielded a sparse assemblage of fossil pollen and spores. Latest Paleocene age is indicated by numerical dominance of Caryapollenites veripites. Other species present include:

*Alnus speciipites*

*Caryapollenites inelegans*

*Laevigatosporites ovatus*

*Lanagiopollis lihokus*

*Momipites wyomingensis*

*Triporopollenites sp."*

This latest Paleocene age is comparable to the late pollen zone P6 ages previously reported from just below the Denver Basin paleosol. This pollen collection could be interpreted to indicate that, at this location near Sellers Gulch about 2.5 miles southeast of the town of Castle Rock, no more than about 150 feet of the upper part of the Dawson Arkose could be Eocene age, or younger than pollen zone P6.

**Figure 26. Location where pollen sample CRS-04 was collected (NE¼SE¼ sec. 24, T. 8 S., R. 67 W., Castle Rock South quadrangle). Thin beds of brown organic-rich fine-grained sandstone and clayey siltstone were exposed during road construction in 2004, but the collection site has since been re-contoured and buried with soil.**

The strata that have been mapped as the Dawson Arkose in the Castle Rock area have been included within Raynolds' (1997, 2002) D2 sequence. That work, and Reynolds and Johnson (2003), has lead us to expect that almost the entire thickness of the Dawson Arkose is Eocene in age, with just very thin deposits of Paleocene pollen zone P6 age at the base of the Dawson Arkose. The above four pollen collections, clearly indicate that the age of the strata mapped as Dawson Arkose in the Castle Rock area is incompletely understood. None of these recent collections indicates an Eocene age for the Dawson Arkose, as would be expected from previous work. A possible explanation for the anomalous ages for the Dawson Arkose/D2 sequence in the Castle Rock area is a peripheral unconformity around the edges of the Denver Basin, where the late middle to latest Paleocene strata were removed by erosion. Persistent subsidence of the basin through the late middle and later Paleocene preserved strata in the Castle Rock area that were removed from the edges of the basin during the erosion and weathering that formed the Denver Basin paleosol. **Figure 27** is a cartoon sketch of possible basin development from middle Paleocene through Eocene in which late Paleocene deposits were preserved in the center of the basin, while an unconformity was formed around the margins.

The type locality of the Dawson Arkose remains, as much as possible, that initiated by Richardson (1915) when he first used the name. Thus, the type locality of the Dawson Arkose remains at Dawson Butte, but is restricted to the section of arkosic sandstone on Dawson Butte (sec. 6, T. 8 S., R. 67 W.) above the regional Denver Basin paleosol described by Farnham (2001) and Farnham and Kraus (2002) and below the unconformity at the base of the Castle Rock Conglomerate. Excellent exposures of these strata can be seen in gullys, particularly on the west side of Dawson Butte.

The sandstones and arkoses of the Dawson Arkose in the Castle Rock area are generally stable and should have good foundation characteristics. The finer-grained, more clay-rich lithologies should be expected to be less stable and may have high shrink-swell potential. Occasionally, parts of the Dawson Arkose are well cemented and stand out as cliffy outcrops that may be rock fall and block failure hazards to structures or improvements built below.

# EOCENE UNITS

Three Eocene map units are included on the map in Plate 1 and 2 in the southwestern Denver Basin; the Larkspur Conglomerate, the Wall Mountain Tuff; and the Castle Rock Conglomerate. Although not part of the synorogenic sedimentary rocks filling the Denver Basin (those that I herein named the Denver Basin Group that are the primary focus of this report) the distribution of these Eocene units may contain clues to the deformation history of the Basin. For that reason, the Eocene units are shown on Plate 1 and 2, and descriptions of the lithologies and distribution of these younger map units has been included in this report.

### Larkspur Conglomerate (Tlc)

The Larkspur Conglomerate (Tlc) is a newly named unit of Eocene age that underlies the late-Eocene-age Wall Mountain Tuff on Larkspur Butte (**figures 28, 29**). In preliminary maps and reports for CGS this unit has been informally

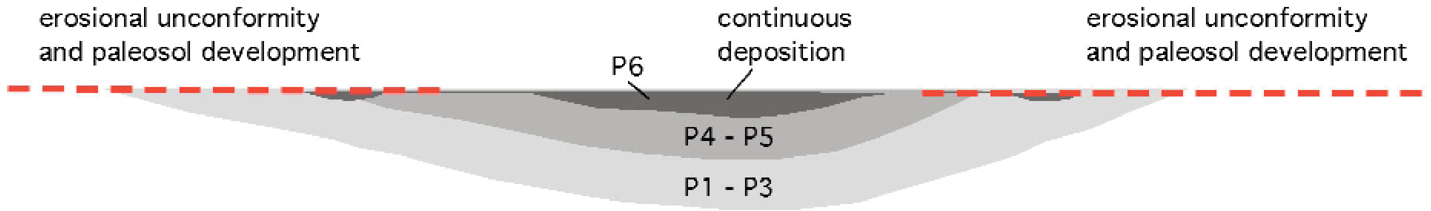



**Figure 27. Possible configuration of the Denver Basin at the end of the Paleocene Epoch. Erosion and paleosol formation has removed parts of the strata of pollen zone 1 - 3 in the peripheral edges of the basin; strata from pollen zones P4, P5, and P6 were either eroded or not deposited from an intermediate area of the basin; continuous deposition in the center of the basin has allowed a complete record of Paleocene pollen zones to accumulate. Eocene age Dawson Arkose strata were then deposited across the entire basin. In this sketch the area of continuous deposition in the center of the basin has been greatly exaggerated in size.**

named the "conglomerate of Larkspur Butte". The unit is here formally named after the site of its original description by Richardson, 1915.

The presence of a conglomerate unit beneath the Wall Mountain Tuff ("rhyolite"), was recognized by Richardson, 1915, p.7, who wrote:

"An unconformity in the Dawson arkose of more than usual prominence is exposed near the top of a number of the buttes that are capped by rhyolite in the vicinity of Larkspur and Greenland. The following section, measured on Larkspur Butte, is typical:

Section of the upper part of Larkspur Butte

| | Feet |
|---|---|
| Rhyolitic rocks, capping hill ---------- | 30± |
| Arkose, reddish, conglomeratic; containing fragments of white arkose like the underlying beds and pebbles of granite, quartz, quartzite ------------------------------ | 25± |
| Unconformity, uneven eroded surface. | |
| Arkose, whitish, fine textured --------- | 25± |

This unconformity evidently records changed conditions "

**Figure 28. Larkspur Butte viewed from the southwest; top of the butte is composed of about 25 to 30 feet of Wall Mountain Tuff overlying 30 to 40 feet of Larkspur Conglomerate. The type locality of this newly named unit is located on the southwest side of this butte in SW¼ NW¼ sec. 35, T. 67 W., R. 9 S.**

Richardson's description implies that he thought the Larkspur Conglomerate was a part of the Dawson arkose (lower case "a" in arkose was Richardson's terminology), and the unit has been so regarded by some subsequent mappers. The Larkspur Conglomerate can be found on most of the high buttes in the Greenland quadrangle, as Richardson noted. A very small channel filled with Larkspur Conglomerate was found west of the town of Larkspur on Monkeyface Butte (Thorson and others, 2008). The unit occurs farther to the north beneath some of the remnants of Wall Mountain Tuff in the Castle Rock South, Castle Rock North, and Russellville Gulch quadrangles (Thorson, 2004, 2005, 2006). Other occurrences with less clear relationships to the Wall Mountain Tuff can be found on the Dawson Butte quadrangle (Morgan and others, 2004), Sedalia quadrangle (Morgan and others, 2005); and Black Forest, Cherry Valley School, and Ponderosa Park quadrangles (Thorson, 2003, 2004, 2007). The distribution of the Larkspur Conglomerate, and its potential significance to interpretation of the tectonic history of the rise of the Front Range, has required that the unit be mapped separately, and given its formal name. The unit has previously been mapped, somewhat inconsistently, as either part of the "Dawson Formation" or as part of the Castle Rock Conglomerate (Trimble and Machette, 1979a,b; Bryant and others, 1981).

The Larkspur Conglomerate is a brown, pinkish-brown, or pink arkosic conglomerate and pebbly arkose unit that was previously included in the top part of the upper Dawson Formation (Richardson, 1915; Trimble and Machette, 1979a; Morse, 1979). It is predominantly composed of pebbles, cobbles, and occasionally boulders of pink granite or pink feldspar in a coarse sand-size to pebble-size matrix of quartz and pink feldspar. Minor interbeds of coarse to very coarse light-brown sandstone occur locally. The unit is strongly cross-bedded. Clasts of gray or white quartz, gneiss, quartzite of various colors, red sandstone, and chert are common. Large clasts of eroded Dawson Arkose arkose, up to 3 ft in diameter, are common near the base of the unit. On Larkspur Butte the unit contains granite clasts up to 8 inches in diameter. The clast size decreases southeastward from the type section on Larkspur Butte, until in the Black Forest quadrangle the largest clasts are only about 3 inches in largest dimension (Thorson, 2003). Clast size increases northeast from the type section and coarse cobbles and small boulders are common in the exposures of this unit in the Russellville Gulch and Ponderosa Park quadrangles (Thorson, 2006, 2007).

The Larkspur Conglomerate was deposited on a significant erosional unconformity across the top of the Dawson Arkose. On Larkspur Butte the Dawson-Larkspur contact cuts downward across about 35 to 40 ft of Dawson strata and appears to be the edge of a steep-walled paleovalley filled with Larkspur Conglomerate (**figure 29**). The Wall Mountain Tuff rests on the Larkspur Conglomerate over the filled paleovalley but was deposited directly on the Dawson Arkose outside this and many other paleovalleys. Similar paleovalley-filling relationships were found on Corner Mountain, Nemrick Butte, Rattlesnake Butte, True Mountain, and an unnamed butte in NE¼ sec. 7, T. 10 S., R. 66 W.

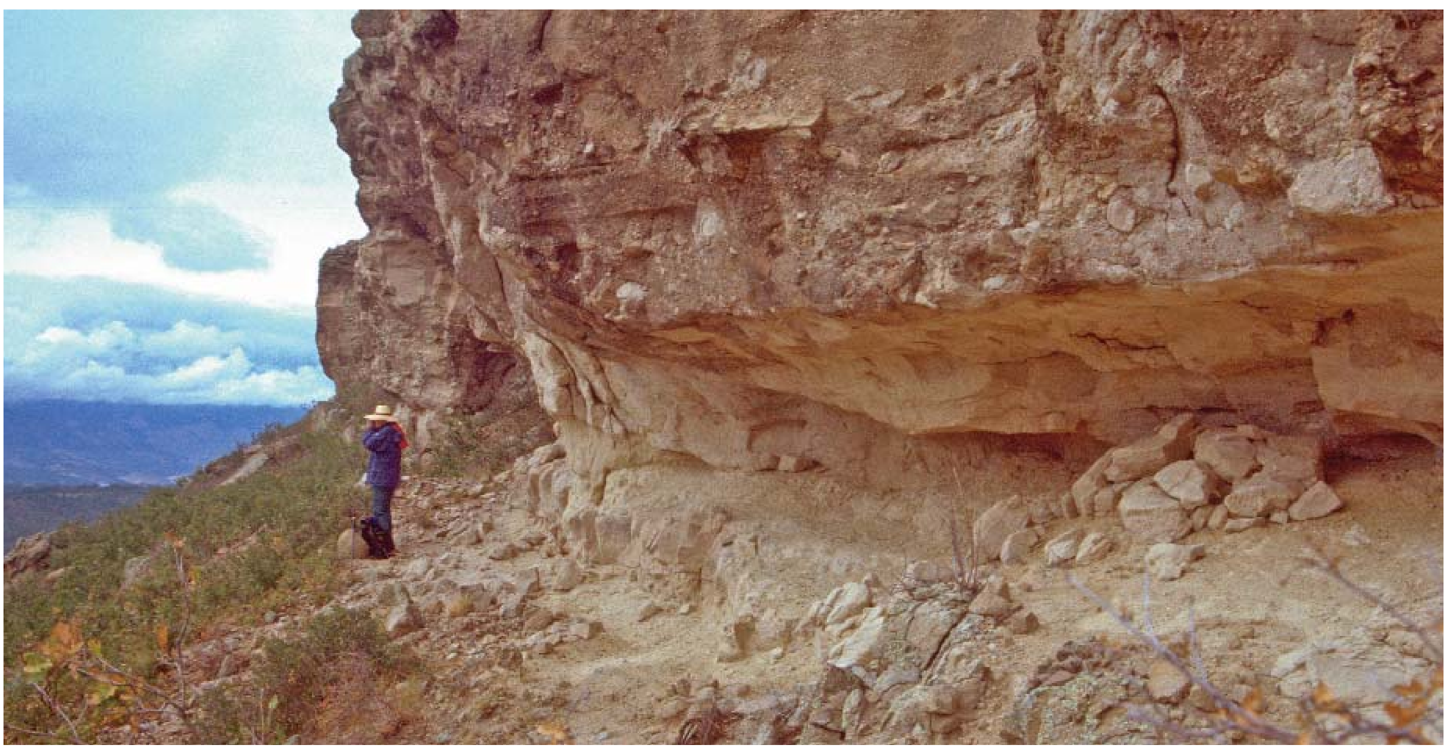


**Figure 29. Erosional unconformity between the Larkspur Conglomerate and the underlying Dawson Arkose at the type locality of the Larkspur Conglomerate on the southwestern side of Larkspur Butte.**

The Larkspur Conglomerate is lithologically distinct from strata above and below. The Dawson Arkose strata below the contact are finer grained, predominantly arkose and pebbly arkose that seldom contains pebbles larger than 3/4 inch. The Dawson arkose and pebbly arkose also has a very high content of light-colored sandy clay matrix filling inter-granular spaces between coarse sand or pebble clasts. The Larkspur Conglomerate at the type section is distinctly matrix-poor and has well preserved, empty, inter-granular pores between pebble-size clasts. In a man-made exposure in the NE part of the Russellville Gulch quadrangle (NE¼ NE¼ sec. 16, T. 8 S., R. 65 W., a cut-bank in the yard of an aggregate plant, south side of Highway 86 just west of the Douglas-Elbert County boundary) the Larkspur Conglomerate has a greater amount of greenish clayey matrix than at the type section. At this northeastern location the unit also contains 10 to 15% well rounded cobbles of weathered or altered andesitic or dacitic volcanic rocks. These volcanic cobbles are not Wall Mountain Tuff, and may be from the source area of the Larkspur Conglomerate in the Front Range or farther to the west.

The Larkspur Conglomerate is overlain by either Wall Mountain Tuff or by Castle Rock Conglomerate. The Wall Mountain Tuff is a light-gray, light-brown, or lavender-gray fine-grained welded tuff with small phenocrysts of sanidine and biotite. The Castle Rock Conglomerate is similar in appearance to the Larkspur Conglomerate, but contains clasts of Wall Mountain Tuff.

The Larkspur Conglomerate has a different alteration history than the Dawson Arkose. Most of the feldspar in the Dawson, either as individual grains or in granite clasts, has been bleached white, light gray, or cream colored and partially altered to clay by diagenetic or weathering processes. Feldspars in the Larkspur Conglomerate are unaltered and retain the pink, light-red, or reddish-brown color characteristic of the Pikes Peak Granite. The difference in alteration history of these two units suggests that there is significant time represented by the erosional unconformity at the contact. During this time the uppermost Dawson Arkose was deposited, altered, and eroded before the Larkspur Conglomerate was deposited. The bleaching alteration event does not affect any of the rocks younger than the Dawson Arkose so it must have been completed before deposition of the Larkspur Conglomerate. Thus, there appears to be a significant (but not yet resolved) age difference between the upper Dawson Arkose and the Larkspur Conglomerate.

The Larkspur Conglomerate represents the geological and topographical conditions just before the deposition of the Wall Mountain Tuff. The Larkspur Conglomerate is considerably coarser than pebble conglomerates in the Dawson. This, and the unconformity, suggests that the Front Range began a cycle of uplift in the Eocene before the eruption of the Wall Mountain Tuff. The Wall Mountain Tuff ignimbrite appears to have been a single ash flow event that flowed over an undulating surface of relatively low relief eroded across the upper Dawson Arkose. The larger stream valleys on this surface, those that drained the rejuvenated mountains, were at least partially filled with cobble to boulder gravel eroded from the uplifted mountain sources. This gravel eventually became the Larkspur Conglomerate.

The Larkspur Conglomerate is most likely of late Eocene age; it lies beneath late Eocene-age Wall Mountain Tuff and above the Dawson Arkose whose deposition extend into the Eocene. It is of probable late Eocene age because a significant part of the Eocene epoch probably passed during the deposition, alteration, and erosion of Dawson Arkose. And, because the Larkspur Conglomerate fills, or partially fills, paleovalleys that were present in the late Eocene and appear to have influenced the deposition of the Wall Mountain Tuff.

### Wall mountain Tuff (Twm) - 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 it 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. Small float fragments of yellowish-green clayey devitrified tuff were found occasionally near the base of the welded tuff unit, but this material was not found in an exposure. The Wall Mountain Tuff was deposited as an ash-flow that was hot enough that the ash compacted and welded into a viscous plastic after emplacement. In places the welded ash flowed and developed flow-layering before cooling and solidifying.

The Wall Mountain Tuff has been dated as about 36.7 million years in age by McIntosh and others, 1992; McIntosh and Chapin, 1994. The ash may have been erupted from the Thirtynine Mile volcanic field (Epis and Chapin, 1974), or perhaps from the Sawatch Range. The ignimbrite 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 (million years before present; Mcintosh and others, 1992; Mcintosh and Chapin, 1994). However, the age for the end of the Eocene is now defined to be 33.7 mybp (figure 3) so the Wall Mountain Tuff should now be considered to be late Eocene.

The Wall Mountain Tuff is about five to 50 feet thick. It caps many of the higher buttes in the Larkspur, Greenland, Cherry Valley School, Dawson Butte, Castle Rock South, Sedalia, Castle Rock North, and Russellville Gulch quadrangles as a flat or very gently sloping deposit resting either on the Larkspur Conglomerate or on Dawson Arkose. The general aspect of most of these exposures suggests that the outcrops of Wall Mountain Tuff are the remnants of deposits that once filled stream valleys in several drainage systems. The surface on which these drainage systems were developed can be reconstructed using the approximate elevation of the base of the Wall Mountain Tuff in exposures across its area of preservation (**figure 30**). This reconstruction indicates that Wall Mountain Tuff was deposited on a surface that now

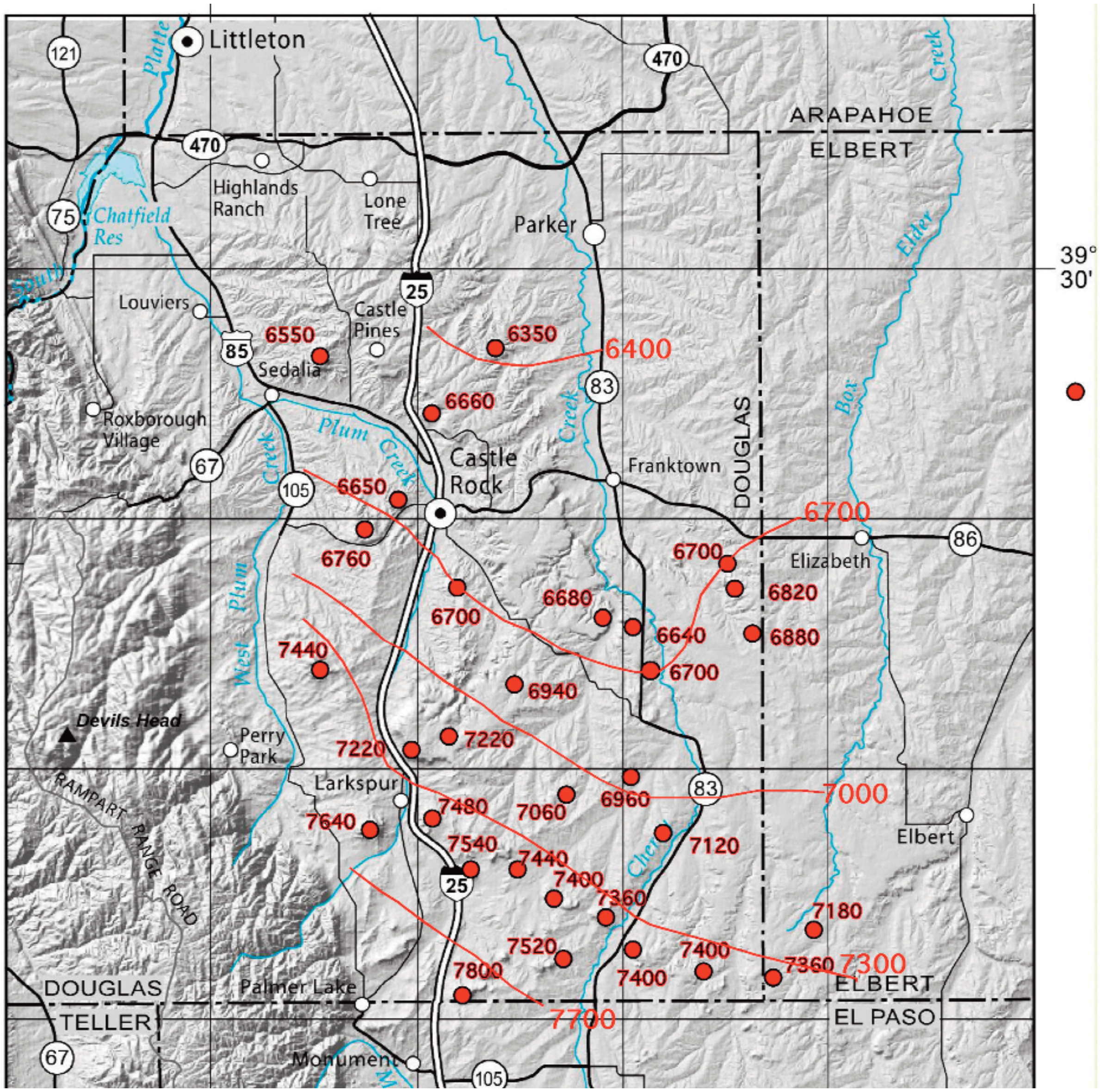



**Figure 30. Reconstruction of the northeast-sloping surface on which the Wall Mountain Tuff was deposited. This reconstruction was made by contouring the approximate elevations of the base of the welded tuff in the outcrops indicated. The base for this reconstruction is the north part of the digital elevation diagram shown in figure 2; elevations and contours are in ft.**

slopes gently towards the north-northeast at a gradient of about 70 feet per mile.

On most outcrops the welded tuff is fractured horizontally into hackly plates generally about 4 to 8 inches thick. Most of the significant outcrops of Wall Mountain Tuff have been tested long ago for their potential as building stone quarries; small overgrown test pits are common on the outcrops. In the early 1900s "rhyolite" quarries were common in the Castle Rock area on the Dawson Butte and Castle Rock South quadrangles. Two quarries, producing building stone and aggregate from the Wall Mountain Tuff (locally called the Castle Rock rhyolite) are still in operation in SE¼ sec. 29, and SW¼ sec. 27, T. 8 S., R. 66 W.

### Castle Rock Conglomerate (Tcr) - late Eocene

The Castle Rock Conglomerate is a pebble, cobble, and boulder arkosic conglomerate composed predominantly of sub-round to round fragments of pink and gray granite, pink feldspar, and quartz with subordinate amounts of gneissic metamorphic rocks, quartzite, red sandstone, welded tuff, and chert in a coarse to very coarse sand matrix of quartz and feldspar grains. The distinguishing characteristic of this unit is the presence of angular to sub-angular pebble- to boulder-size clasts of gray, brownish-gray, maroon, or lavender-gray welded tuff, which have been eroded from deposits of the Wall Mountain Tuff (**figure 31**). Outcrops of this unit are usually very strongly cross-bedded.

**Figure 31. Castle Rock Conglomerate exposed in a road cut along Highway 83 (NE¼ sec 24, T. 8 S., R. 66 W.) showing sub-angular blocks of Wall Mountain Tuff in light-brown pebble and cobble conglomerate with sub-round to well-rounded cobbles of gneiss, quartzite, and pink granite; hammer handle is 15 inches long.**

The Castle Rock Conglomerate is younger than the Wall Mountain Tuff, which has been dated at about 36.7 my (Mcintosh and others, 1992; Mcintosh and Chapin, 1994). It must be older than the end of the Eocene (33.5 my; figure 2) since it contains bones of titanotheres (late Eocene, K.R. Johnson, Denver Museum of Nature and Science, written commun. 2002).

The Castle Rock Conglomerate reaches a thickness of at least 120 feet in parts of the Russellville Gulch quadrangle. Morse (1985) has reported greater thickness of the unit, up to 230 feet, but does not cite a location for this thick section. The thickness of the sections published by Morse (1985, figure 12, p. 284; up to 135 feet) agree well with observations in the Russellville Gulch quadrangle. Since Morse lumped the Larkspur Conglomerate together with the Castle Rock Conglomerate, as did previous published works (for example, Trimble and Machette, 1979; and Bryant and others, 1981), it is possible that his thick sections include both conglomerate units.

In most exposures of the Castle Rock Conglomerate, the unit is a continuous sequence of cross-bedded pebble to cobble conglomerate (**figure 32**) with a common layer of boulder conglomerate at the base (**figure 33**). In a few sections the conglomerate was found to be a series of two or three stacked upward-fining sequences crudely graded from cobble conglomerate to pebbly sandstone. In the Franktown area there are upper and lower members of the Castle Rock Conglomerate separated by 40 to 50 feet of recessive yellowish-green to greenish-gray mudstone and sandy mudstone. The section exposed along Highway 83 (**figure 34**, SW¼ SW¼ sec. 13, T. 8 S., R. 66 W.; about 3 miles south of Franktown) is the only well exposed section showing this mudstone unit, but many of the exposures within about 3 miles of Franktown have two ledges of conglomerate separated by a recessive slope with clayey soils. From this observation, the area containing the recessive middle Castle Rock unit is projected to be several miles in diameter. This recessive middle member of the Castle Rock Conglomerate indicates that the unit is not simply a series of flood events, but also incorporated some slack-water, low energy environment during otherwise very energetic deposition.

The Castle Rock Conglomerate was deposited as one or more large sheets that filled paleovalleys on an erosion sur-

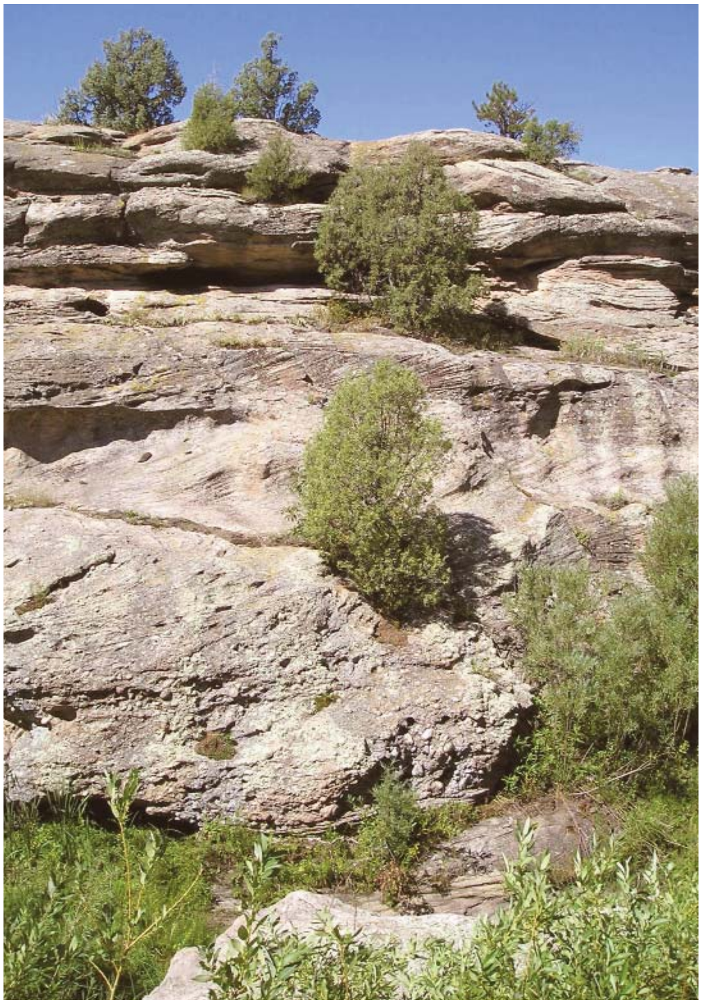
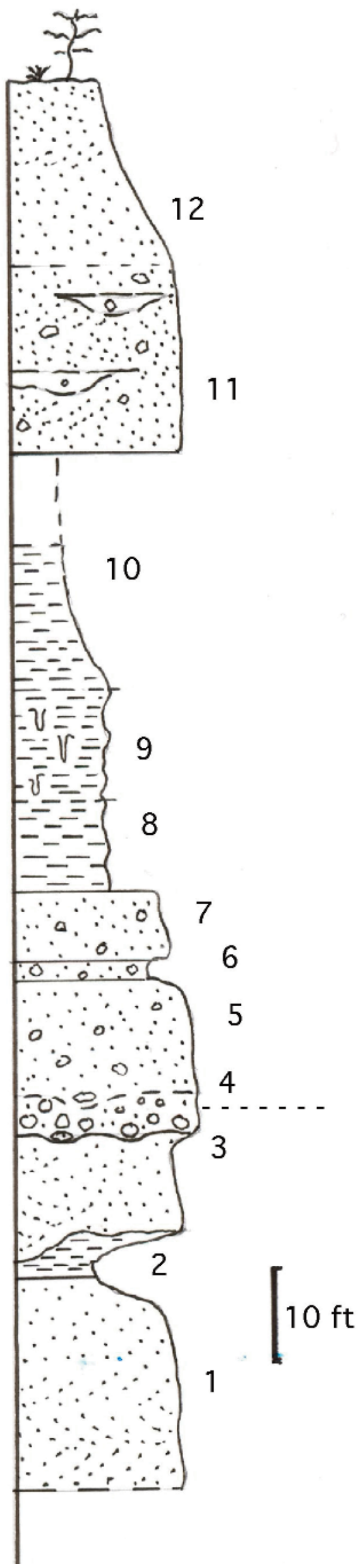


**Figure 32. Castle Rock Conglomerate exposed in the banks of Cherry Creek (NW¼ sec. 7, t. 9 S., R. 65 W.) showing the characteristic strong cross bedding and a cobble conglomerate layer at the base; exposure is about 30 feet high.**

face cut across the top of the Dawson Arkose, Larkspur Conglomerate, and Wall Mountain Tuff. In many areas the deposits of Castle Rock Conglomerate that fill paleovalleys have almost-flat, gently sloping upper surfaces that appear to be exposed bedding surfaces of original depositional sheets. Using these depositional surfaces to reconstruct the top of the original paleovalley fill one can reconstruct a paleovalley system similar to that shown in **figure 35**. These paleovalleys slope gently to the north and northwest from elevations between 7500 and 7700 ft in the Black Forest quadrangle, above 7200 ft on Hunt Mountain in the southeast corner of the Dawson Butte quadrangle, and above 6600 on Cherokee Mountain in the Sedalia quadrangle, to below 6350 ft in the northern part of the Castle Rock North quadrangle.

Conflicting interpretations of the direction of stream flow in the Castle Rock Conglomerate system have been published. Desborough and others (1970) determined that in an area near Castle Rock cross bedding directions indicated stream flow directions that varied from northwest to southeast and averaged about east-northeast. Morse (1985) published a diagram showing that over a larger area cross bed dip directions indicated generally eastward flow in Tcr streams. Recently, Evanoff (2007) has proposed that current flow was from northwest to southeast based on cross bedding, clast size, and clast provenance.

**Figure 33. Basal contact of the Castle Rock Conglomerate with boulder conglomerate layer deposited on an erosional surface at the top of the Dawson Arkose (Franktown grade section, SW¼ SW¼ sec. 13, T. 8 S., R. 66 W.); staff for scale is 5 feet long. Boulder conglomerate unit resting on the white Dawson Arkose is unit #4 in figure 34.**




## FRANKTOWN SECTION

measured along Highway 83, about 3 miles south of Franktown
SW1/4 SW1/4 sec. 13, T. 8 S., R. 66 W.
top E523007 N4354878 UTM m, NAD 27 zone 13

## CASTLE ROCK CONGLOMERATE

12. lt brn pebble cgl, as below, measured above road cut

11. lt brn pebble cgl, massive to cross bedded, thick to very thick bedded, some flat laminated; large claystone clasts to 36" weather out, sub-ang pebbles Twm to 2"

10. greenish-gray to grayish-green mudstone, recessive, top 10 ft covered by slumped blocks from above

9. lt greenish-gray sandy mudstone, massive, highly bioturbated

8. grayish-green and yellowish-green mudstone, recessive, poor exposure

7. lt brn crs ss and pebble cgl, variably cemented; few large sub-rnd pebbles to 4", few Twm clasts to 6"

6. lt brn cobble cgl, as below, recessive

5. lt brn pebble cgl, cross bedded, similar to matrix in unit below, occasional layers of cobble cgl; well rounded cobbles to 6", sub-ang clasts of Twm to 18", grades into unit below

4. lt brn to gray boulder and cobble cgl, sub-rnd to rnd cobbles and boulders of gneiss, quartzite, red granite, rare chert, to 12", sub-ang clasts Twm to 36"; sharp contact at base

## DAWSON ARKOSE

3. wht to very lt brn pebbly very crs ss, in part cross bedded, very clayey at top; channel cut into unit below, contains large clasts of yellow green mudstone in base, variable resistance to weathering

2. yellow-green mudstone; gradational to unit below, sharp erosional contact at top

1. wht pebbly ss and pebble cgl, clay rich, massive near top, bottom cross bedded, a few pebbles of sub-ang to sub-rnd granite to 2"

base section E522680 N4355543

**Figure 34. Franktown grade section of Castle Rock Conglomerate measured along Highway 83 (SW¼ SW¼ sec. 13, T. 8 S., R. 66 W.; about 3 miles south of Franktown).**

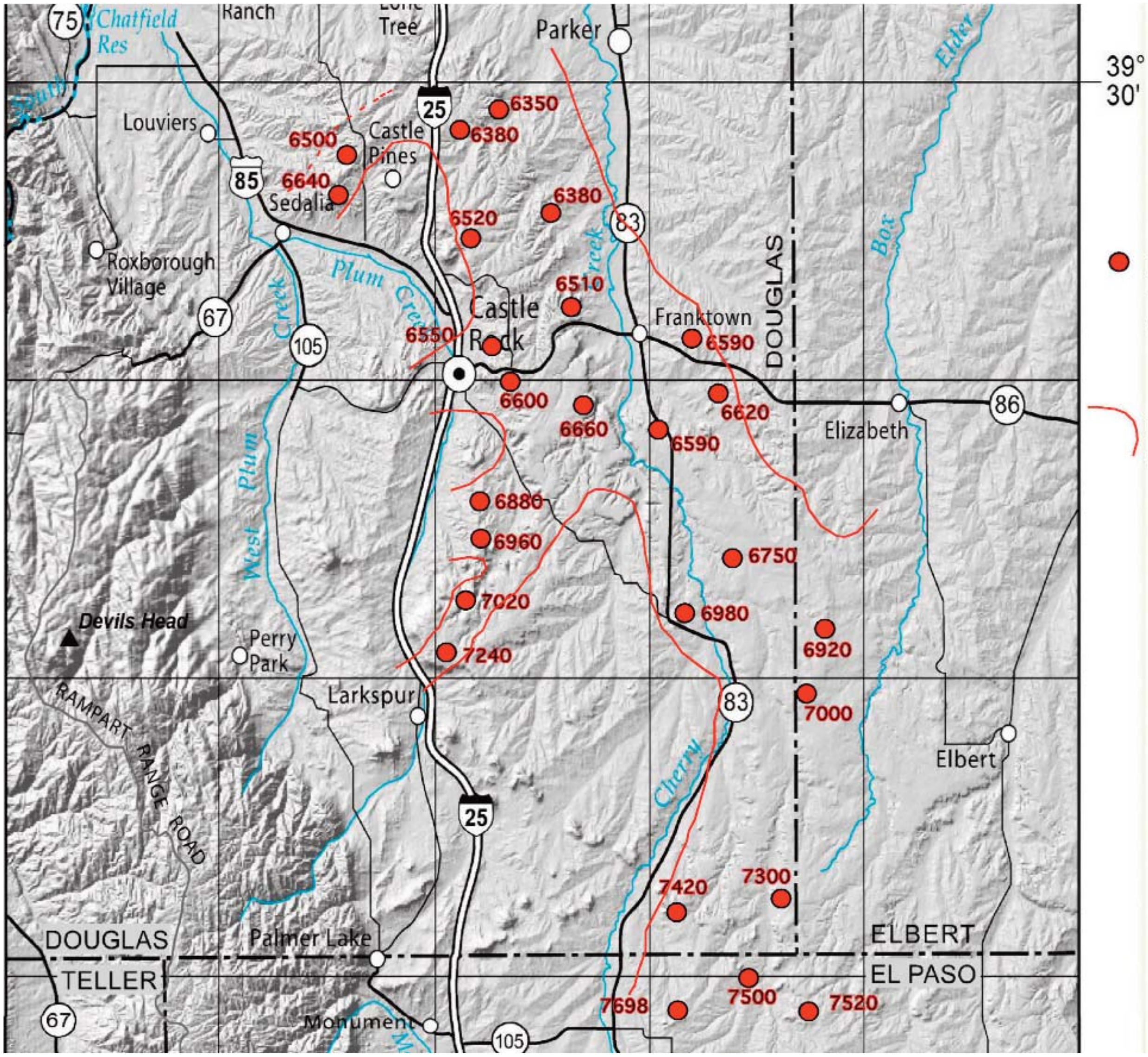



**Figure 35. Castle Rock Conglomerate paleovalleys reconstructed by using the elevation of near-flat upper surfaces of Castle Rock Conglomerate deposits, and mapped or projected edges of exposed paleovalleys.**

The present slope of the main Castle Rock Conglomerate paleochannels, from the northern part of the Black Forest quadrangle to the northern part of the Castle Rock North quadrangle, is about 1150 ft in 30 miles (about 40 ft per mile) in a northwesterly direction (figure 35). Evanoff's hypothesis requires a reversal of the channel slope since its erosion, to a similar magnitude slope to the southeast. This "Evanoff reversal" hypothesis, from about 40 ft/mile to the northwest (present slope) to 40 ft/mile to the southeast (original slope) requires an uplift of the southern part of the Denver Basin of about 2200 ft since the Eocene. Evanoff's reversal, when applied to the erosion surface underlying Wall Mountain Tuff (figure 30), would rotate the slope of the Wall Mountain Tuff to flat or easterly dipping.

Many additional current direction measurements have recently been collected by Matt Morgan and Steven Kelller for the Colorado Geological Survey (M. Morgan, personal commun., 2010). Hopefully these new measurements will help clear the confusion about the stream flow direction during Castle Rock Conglomerate time.

The map that accompanies this report shows the distribution of Castle Rock Conglomerate to be much less than shown by previous authors. Trimble and Machette (1979a) and Bryant and others (1981) show the Castle Rock Conglomerate to cap the ridge between the drainage of East Cherry Creek and Gold Creek (between the towns of Franktown and Elizabeth). I, too, have mapped a conglomerate unit there but have assigned the ridge-capping conglomerate to the Larkspur Conglomerate for the following reasons. First, it stands higher in the topography than the Castle Rock Conglomerate, by about 100 feet. Second, on buttes in sec. 17, 20, and 21, T. 8 S., R. 65 W. and sec. 22, 27, and 34, T. 8 S., R. 65 W. this ridge-capping conglomerate was found to lie beneath the Wall Mountain Tuff. And, third, the ridge-capping conglomerate, although very coarse and bouldery, was not found to contain any clasts of Wall Mountain Tuff. Thus the Castle Rock Conglomerate, as mapped in the Russellville Gulch quadrangle (Thorson, 2006), is the remains of a deposit that filled an ancient paleovalley, which trended north-northwest roughly paralleling the present Cherry Creek valley. This Castle Rock paleo-valley is younger than, and eroded downward through, deposits of the older Larkspur Conglomerate in the Russellville Gulch quadrangle.

# PETROGRAPHY AND GEOCHEMISTRY OF THE DENVER BASIN VOLCANIC PEBBLES

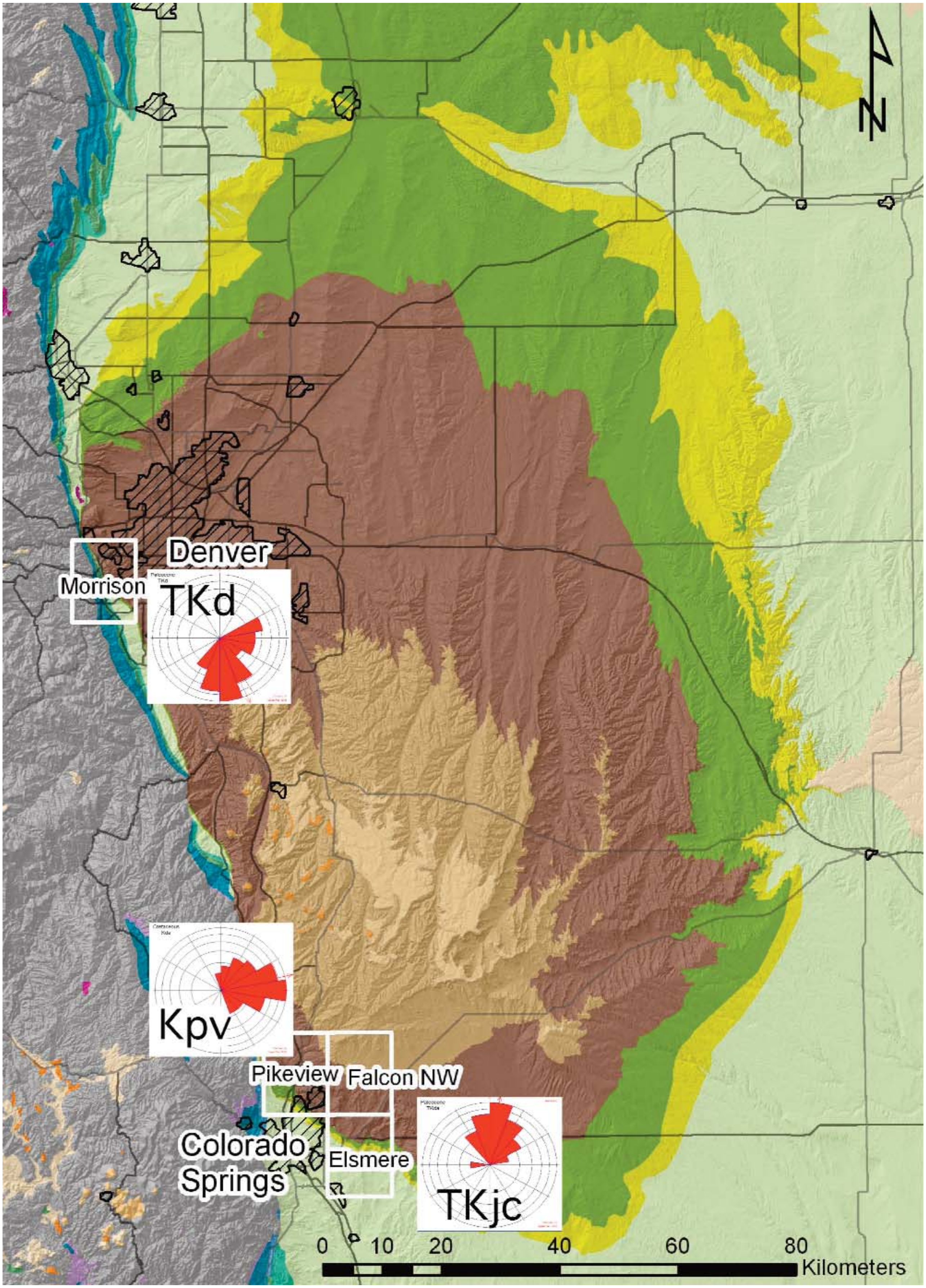
The origin of the volcanic pebbles in the Pikeview, and Jimmy Camp Formations in the Colorado Springs area, and their relation to volcanic pebbles in other units of the Denver Basin has been investigated, in part through the mapping by CGS and summarized in this report. Additional funding and support for this specific study was provided by the Denver Museum of Nature & Science (DMNS) through a grant from the National Science Foundation. DMNS has graciously agreed that the data and interpretations of the petrography and geochemistry of volcanic pebbles in the Denver Basin, originally presented at a DMNS-organized symposium (Thorson, 2007b), could be formally presented in this report.

A summary diagram from Thorson (2007b) showing the paleocurrent directions, discussed in previous sections on the Pikeview Formation (Kpv) and the Jimmy Camp Formation, is presented as **figure 36**. A third major input source for volcanic pebbles in the Denver Basin was in the Denver Formation (Tkd) in the Morrison quadrangle , where volcanic pebbles and cobbles were being introduced into the Denver Basin and spread out by streams flowing to the south and east. The data for the Denver formation has been added to the data from the Kpv unit (Pikeview and Elsmere quadrangles) and Jimmy Camp Formation (TKjc, Elsmere, Falcon NW, and Pikeview quadrangles) in figure 36. The earliest input of conglomerates with a large proportion of volcanic pebbles was from the west-southwest in the Upper Cretaceous Pikeview Formation unit in the Pikeview quadrangle. Later, in the latest Cretaceous to early Paleocene, when the source of volcanic components had been cut off by the rise of the Front Range and the mountain front deposits were dominated by arkoses of the Pulpit Rock Formation, volcanics from a petrographically and geochemically different source were introduced into the basin from the south in the Elsmere, Falcon NW, and Pikeview quadrangles as the Jimmy Camp Formation (TKjc). During a similar time, latest Cretaceous to early Paleocene, volcanic pebbles and cobbles of a still different source were being introduced into the Denver Basin from the west and spread out towards the east and south in what is now the Morrison quadrangle.

The following procedures were used in the investigation of the volcanic pebbles. The volcanic pebbles in Denver Basin conglomerates and pebbly sandstone units are round to subround, and, although often badly altered, normally weather out of the outcrops as loose pebbles on the surface. When a suitable outcrop was located, the pebbles were examined to describe as many types of volcanic lithologies as possible. A pebble count was made on suitable outcrops by marking a narrow zone on the outcrop and identifying and counting each pebble greater than 1/4 in diameter. Pebble count data for the Kpv and Jimmy Camp units is summarized in earlier sections of this report (see figure 10). The Denver Formation pebble conglomerate and pebbly sandstone contains 87.5% andesite, 5.5% quartz, 4.2% granite, and 2.8% metamorphic pebbles for comparison with the Kpv and Jimmy Camp units in Figure 10.

A composite sample of 50 pebbles of each major volcanic lithology type in a sampled section was collected and submitted to ALS Chemex Assay Laboratories, Sparks, Nevada, for whole rock major element analyses by x-ray fluorescence methods, plus trace elements analyzed by ICP-MS methods. Thin sections were made from representative samples of major lithologies and sent to Petrographic Consultants Inc., Denver, for petrographic descriptions (Hansley and Cookro, 2005a, 2005b, 2006).

**Figure 36 (right). Summary diagram of paleocurrent directions from units containing volcanic pebbles in the southwestern part of the Denver Basin (presented, but not formally published, in Thorson, 2007b). The stratigraphy of the Denver Basin is summarized as Laramie Formation (yellow); Fox Hills Sandstone (green); Denver Basin D1 (Raynolds, 2002) dark brown; Denver Basin D2 (Raynolds, 2002) light brown; and Eocene conglomerates (Larkspur Conglomerate and Castle Rock Conglomerate), tan. Volcanic pebbles in the Kpv unit represent the oldest volcanic source; Upper Cretaceous in age; current rose from figure 9. The volcanic clasts in the Jimmy Camp Formation (TKjc, TKda$_2$ in preliminary reports) and the Denver Formation (TKd) are roughly contemporaneous in age (latest Cretaceous to early Paleocene) but represent different sediment distribution systems, and different volcanic geochemistry. Current direction rose for TKjc from figure 20. Current rose for the Denver Formation (TKd) is a summary of 26 measurements from made in the Morrison and Fort Logan quadrangles; average direction is 148 degrees (S32E). Geological map of the Denver Basin is part of the work of the Denver Basin Project of the Denver Museum of Nature & Science, and used with many thanks.**


N
Denver
Morrison
TKd
Kpv
Pikeview
Falcon NW
Colorado Springs
Elsmere
TKjc
0
10
20
40
60
80
Kilometers

One of the most common methods of describing the chemistry of igneous rocks is plotting $Na_2O$ or $K_2O$, or their sum, against $SiO_2$. Since the volcanic pebbles in the Denver Basin are highly altered, and they have been exposed to diagenetic alteration in fluids rich in potassium and perhaps sodium from altering feldspar in the arkosic lithologies that dominate the Denver Basin, normal petrologic methods for interpreting volcanic rocks would be inaccurate and inappropriate. In the case of highly altered volcanics, other methods for analyzing their geochemical variation have proved to be very successful (Rollinson, 1993; Madeisky, 1995, 1996). These methods are based on minerals and elements stable in the diagenetic alteration environment. Petrography (Hansley and Cookro, 2005a, 2005b, 2006) has shown that the mineral zircon ($ZrSiO_4$) is extremely stable and unaltered in the volcanics. Titanium occurs in several minerals, pyroxene, biotite, and titaniferous magentite or ilmenite particularly, but upon alteration during diagenesis titanium is precipitated as leucoxene ($TiO_2$) very close to its original mineral source, and then remains stable and unaltered. Both petrography and field evidence indicates that silica ($SiO_2$) is quite stable during the diagenesis of Denver Basin rocks. Therefore, three plots using these stable elements or compounds ($SiO_2$, $TiO_2$, and Zr) are presented to illustrate the variation in geochemistry of the Denver Basin Volcanic pebbles (**figures 37, 38, and 39**).

In each of the following plots, each data point represents the analysis of a composite sample of 50 pebbles of a single type of volcanic pebble collected from one single outcrop. Some outcrops contained enough pebbles of more than one volcanic type that some outcrops have more than one data point. The concept that a composite sample of 50 pebbles represents a reliable average composition for one type of volcanic pebble was tested by collecting a composite sample of one volcanic type from an outcrop, and comparing the analysis of that composite of 50 pebbles to the average of 10 analyses of individual large pebbles of the same volcanic type from the same outcrop. The analysis of 50-pebble com-

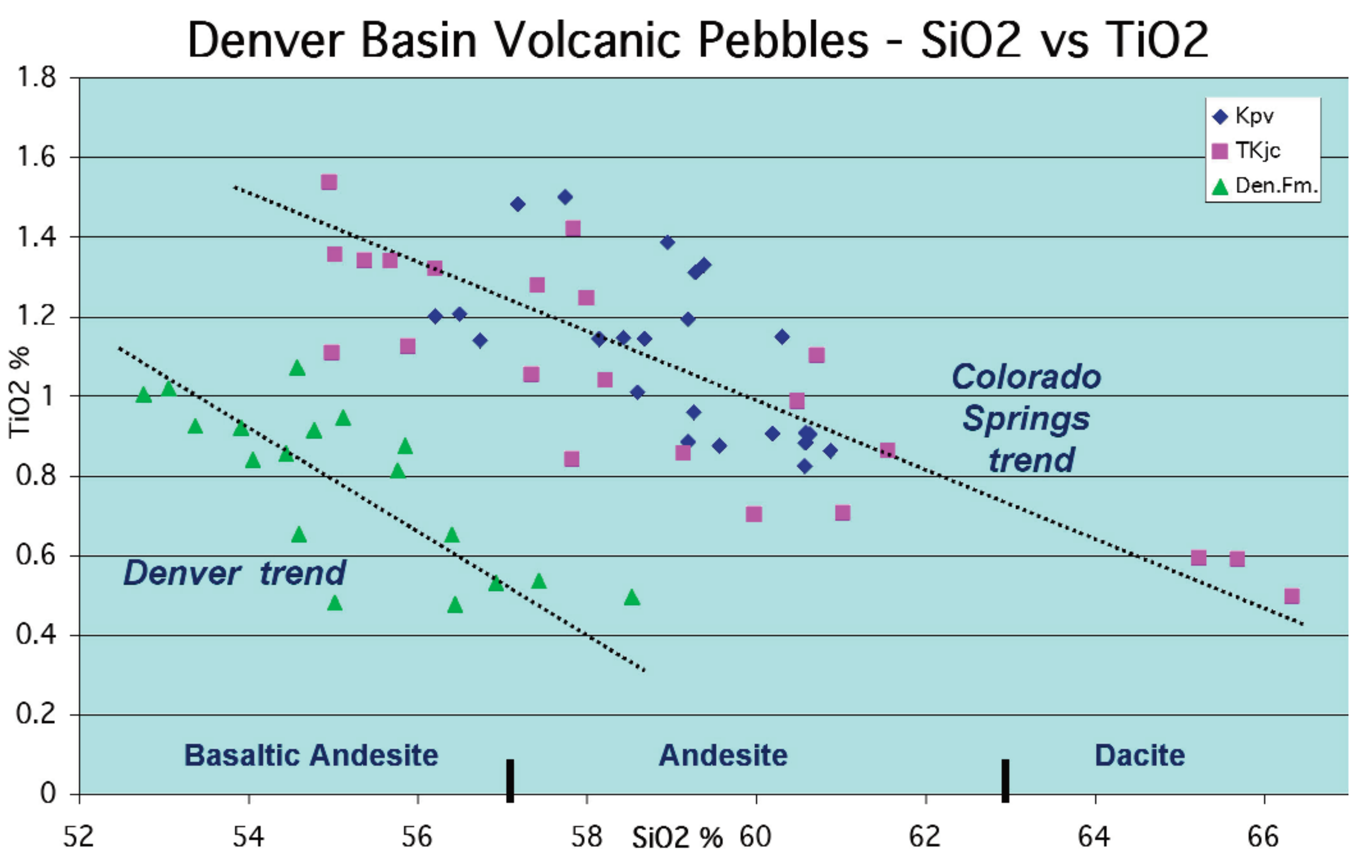



**Figure 37. $TiO_2$ vs $SiO_2$ for Denver Basin volcanic pebbles from the Pikeview Formation Kpv, Jimmy Camp Formation (TKjc), and Denver Formation units. On this plot the two trends suggested indicate that the volcanic pebbles from the Colorado Springs area (Kpv and TKjc) may have originated from the same volcanic source magma, but the later-erupted Jimmy Camp (TKjc) volcanics were more differentiated; higher $SiO_2$, lower $TiO_2$ in the dacite samples. The two tends suggest that the volcanic pebbles in the Denver Formation originated from different andesite volcanic complexes. Each data point represents the analysis of a composite sample of 50 pebbles from a single outcrop; analytical data is "dry" (recalculated without "LOI", the water lost on ignition).**

posite samples was confirmed to compare favorably with the average of single pebbles.

These plots illustrating the "stable element" chemistry of volcanic pebbles in the Denver Basin clearly show that there were more than one, and probably three, different volcanic complexes that supplied volcanic material to the Denver Basin. In the Colorado Springs area, the potential simple explanation that volcanic material was diverted by the rise of the Front Range from a westerly flowing stream system in the Kpv unit, to a northerly flowing stream system in the Jimmy Camp unit, will not hold up. As part of the rise of the Front Range, represented by introduction of the Pulpit Rock Formation arkoses from a granite source, the western edge of the Kpv unit was eroded. There is an overlap in chemistry between the Kpv andesites and those of the Jimmy Camp unit (TKjc) in figure 37, but figures 38 and 39 clearly show that the andesite in the TKjc trend is not simply "recycled" Kpv andesite. A conclusion is clear; there was a separate Paleocene volcanic complex, with more completely differentiated chemistry, different from the Upper Cretaceous andesites of the Kpv unit, somewhere near the southern end of the Denver Basin. It is also clear that the andesite in the Denver Formation came from a different volcanic source than the volcanics introduced into the basin in the Colorado Springs area. The paleocurrent data requires separate stream systems introducing volcanic material from different sources.

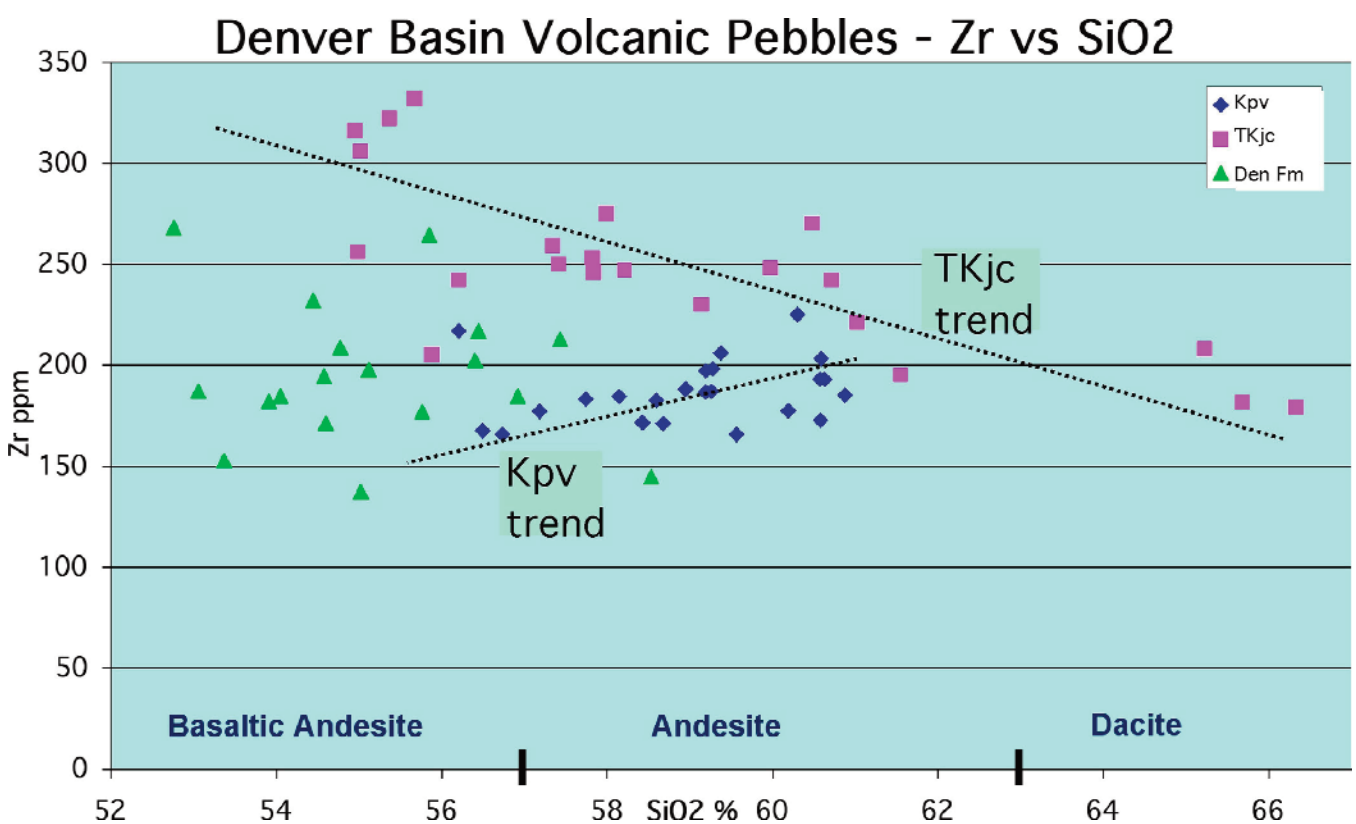



**Figure 38. Zr vs $SiO_2$ for Denver Basin volcanic pebbles from the Pikeview (Kpv), Jimmy Camp (TKjc), and Denver Formations. This plot emphasizes the difference in differentiation trends between the Kpv and Jimmy Camp (TKjc) units in the Colorado Springs area, and the apparent similarity between the andesites of the Pikeview and Denver Formations. The Jimmy Camp samples (TKjc trend) clearly represent material from a separate volcanic complex, which had undergone more differentiation. Each data point represents the analysis of a composite sample of 50 pebbles from a single outcrop; analytical data is "dry" (recalculated without "LOI", the water lost on ignition).**

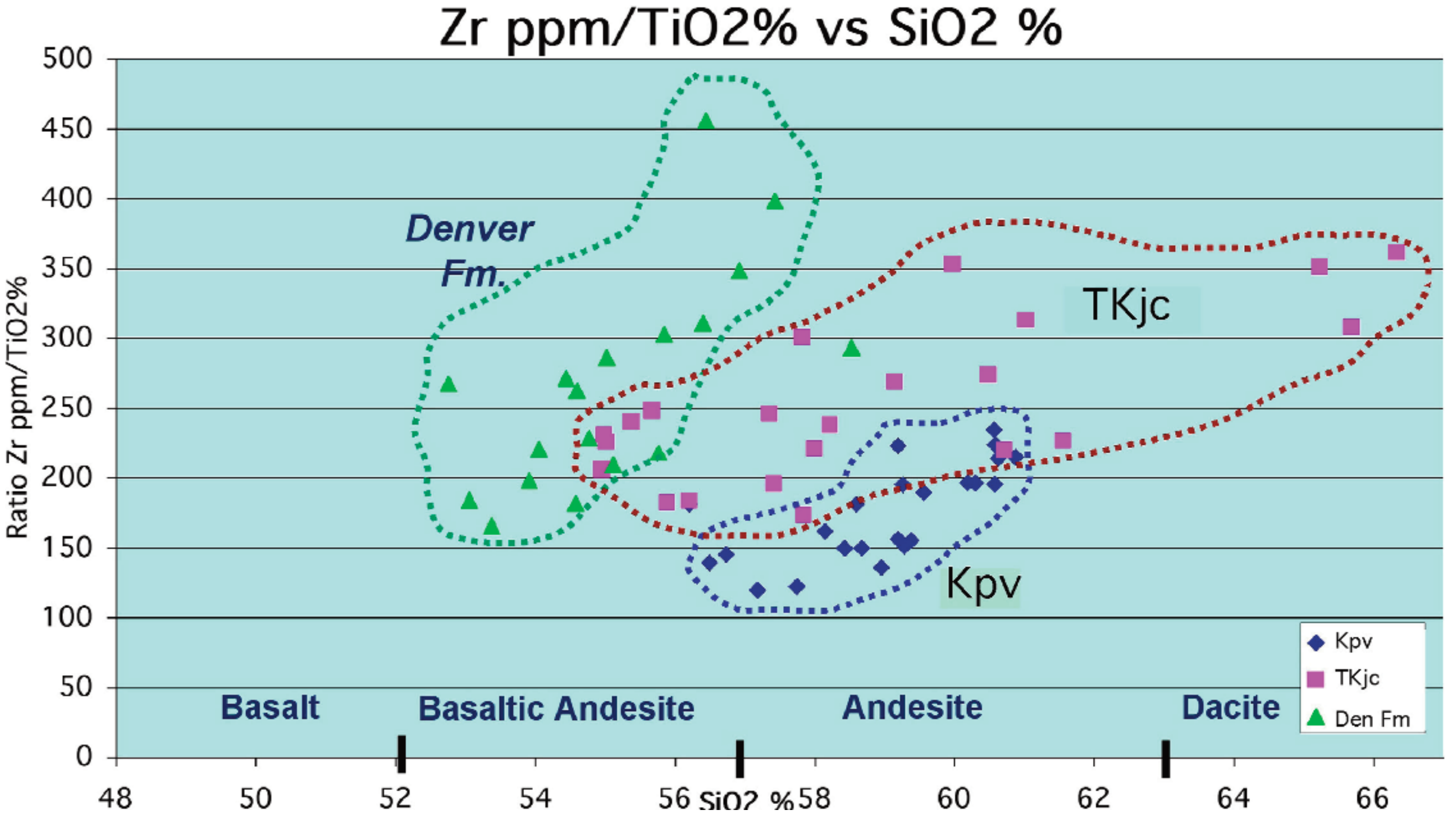



**Figure 39. Ratio of Zr(ppm)/Ti% vs $SiO_2$ for Denver Basin volcanic pebbles from the Pikeview (Kpv), Jimmy Camp (TKjc), and Denver Formations. This plot emphasizes the unique composition of each of the sample populations, and the more primitive chemistry of the andesites from the Denver Formation. Each data point represents the analysis of a composite sample of 50 pebbles from a single outcrop; analytical data is "dry" (recalculated without "LOI", the water lost on ingition).**

# REFERENCES


Barkmann, P.B., Dechesne, M., Wickham, M.E., Carlson, J., Formolo, S., Oerter, E. (in press) Hydrologic cross-sections of the Denver Basin, Colorado: Cololrado Geological Survey, 50p, plus 1:300,000 scale map and 15 cross sections.

Brown, R.W., 1943, Cretaceous - Tertiary boundary in the Denver Basin, Colorado: Geological Society of America Bulletin v. 54, p. 65–86.

Bryant, B., McGrew, L.W., and Wobus, R.A. (1981) Geologic map of the Denver 1x2 degree quadrangle, north central Colorado: U.S. Geological Survey Miscellaneous Investigations Map I-1163, 1:250,000 scale.

Carroll, C.J., and Crawford, T.A., 2000, Geologic map of the Colorado Springs quadrangle, El Paso County, Colorado: Colorado Geological Survey Open-File Report 00-03, scale 1:24,000.

Crifasi, R.R., 1992, Alluvial architecture of Laramide orogenic sediments, Denver Basin, Colorado: Mountain Geologist, v. 29, p. 19–27.

Dane, C.H., and Pierce, W.G., 1936, Dawson and Laramie Formations in the southeastern part of the Denver Basin, Colorado: American Association of Petroleum Geologists Bulletin, v. 20, 1308–1328.

Darton, N.H., 1905, Preliminary report on the geology and underground water resources of the central Great Plains: U.S. Geological Survey Professional Paper 32, 433p.

Desborough, G.A., Raymond, W.A., and Soule, C., 1970, Placer gold of unique fineness in Douglas and Elbert Counties, Colorado: U.S. Geological Survey Professional Paper 700-D, p.D134-D139.

Eberle, J.J., 2003, Puercan mammalian systematics and biostratigraphy in the Denver Formation, Denver Basin, Colorado: Rocky Mountain Geology, v. 38, no. 1, p. 143–169.

Emmons, S.F., Cross, Whitman, and Eldridge, G.H., 1896, Geology of the Denver Basin in Colorado: U.S. Geological Survey Monograph 27, 556 p.

Evanoff, E., 2007, the Castle Rock Conglomerate: Geological Society of America Abstracts with Programs, v. 39, no. 6, p. 26.

Farnham, T.M., 2001, Significance of alluvial paleosols in synorogenic strata of the Denver Basin, CO [Masters thesis]: Boulder, University of Colorado, 134p.

Farnham, T.M., and Kraus, The stratigraphic and climatic significance of Paleogene alluvial paleosols in synorogenic strata of the Denver Basin, Colorado: Rocky Mountain Geology, v.37, no. 2, p. 201–213.

Finlay, G.I., 1916, Colorado Springs folio, Colorado: U.S. Geological Survey Geologic Atlas Folio 203.

Hansley, P.L, and Cookro, T.M., 2005a, Petrography of andesite pebbles from the Dawson Formation: private report, March 14, 2005, Petrographic Consultants International, Inc., Denver, Colorado.

Hansley, P.L, and Cookro, T.M., 2005b, Petrography of the second group of pebbles from the Dawson Formation: private report, October 25, 2005, Petrographic Consultants International, Inc., Denver, Colorado.

Hansley, P.L, and Cookro, T.M., 2006, Petrography of andesite pebbles (from the Denver Formation): private report, May 2, 2006, Petrographic Consultants International, Inc., Denver, Colorado.

Johnson, J.H., 1930, The paleontology of the Denver Quadrangle, Colorado: Colorado Scientific Society Proceedings, v. 12, p.355–378.

Johnson, K.R., Raynolds, R.G., and Reynolds, M.L., editors, 2002, Paleontology and Stratigraphy of Laramide strata in the Denver Basin (Part I): Rocky Mountain Geology, v.37, p. 103–254.

Johnson, K.R., Raynolds, R.G., and Reynolds, M.L., editors, 2003, Paleontology and Stratigraphy of Laramide strata in the Denver Basin (Part II): Rocky Mountain Geology, v.38, p. 1–181.

Keller, J.W., Siddoway , C.S., Morgan, M.L., Route, E., Sacerdoti, R. and Stevenson, A., 2005, Geologic Map of the Manitou Springs Quadrangle, El Paso County, Colorado, Colorado Geological Survey, Denver, CO, Open-File report 03-19.

Keller, J.W., Morgan, M.L., Thorson, J.P., Lindsay, N.R., and Barkmann, P.E., 2006, Geologic Map of the Palmer Lake quadrangle, El Paso county, Colorado: Colorado Geological Survey Open-File Map 06-06.

Krauskopf, K. B., 1967, Introduction to geochemistry: New York, McGraw-Hill, 721 p.

LeRoy, L.W., 1946, Stratigraphy of the Golden-Morrison area, Jefferson County, Colorado: Colorado School Mines quart. v. 41, No. 2, 115p.

Maberry, J.O., and Lindvall, R.M., 1972, Geologic map of the Parker quadrangle, Arapahoe and Douglas Counties, Colorado: U.S. Geological Survey Miscellaneous Investigation Series Map I-770-A, scale 1:24,000.

Maberry, J.O., and Lindvall, R.M., 1977, Geologic map of the Highlands Ranch quadrangle, Arapahoe and Douglas Counties, Colorado: U.S. Geological Survey Geologic Quadrangle Map GQ-1413, scale 1:24,000.

Madeisky, H.E., 1995, Quantitative analysis of hydrothermal alteration, applications in lithogeochemical exploration: unpublished PhD thesis, University of London UK, 268p.

Madeisky, H.E., 1996, A lithogeochemical and radiometric study of hydrothermal alteration and metal zoning at the Cinola epithermal gold deposit, Queen Charlotte Islands, British Columbia, in Coyner, A.R., and Fahey, P.L., eds., Geology and Ore Deposits of the American Cordillera: Geological Society of Nevada Symposium Proceedings, Reno/Sparks, Nevada, April 1995, p. 1153-1185.

Madole, R.F, 2003, Geologic map of the Falcon NW quadrangle, El Paso County, Colorado: Colorado Geological Survey Open-File Report 03-08, scale 1:24,000,

Madole, R.F., and Thorson, J.P., 2002, Geologic map of the Elsmere quadrangle, El Paso County, Colorado: Colorado Geological Survey Open-File Report 02-02, scale 1:24,000.

Morgan, M.L., Siddoway, C.S., Rowley, P.D., Temple, J., Keller, J.W., Archuleta, B.H., and Himmelreich, J.W., Jr., 2003, Geologic map of the Cascade quadrangle, El Paso County, Colorado: Colorado Geological Survey Open-File Report 03-18.

Morgan, M.L., McHarge, J.L., and Barkmann, P.E., 2005, Geologic map of the Sedalia quadrangle, Douglas County, Colorado: Colorado Geological Survey Open-File Report 05-06, scale 1:24,000.

Morgan, M.L., Temple, Jay, Grizzell, M.T., and Barkmann, P.E., 2004, Geologic map of the Dawson Butte quadrangle, Douglas County, Colorado: Colorado Geological Survey Open-File Report 04-07, scale 1:24,000.

Morse, D. G., 1979, Paleogeography and tectonic implications of the late Cretaceous to middle Tertiary rocks of the southern Denver Basin, Colorado: Baltimore, Md., Johns Hopkins University, unpublished PhD thesis, 344 p.

Morse, D.G., 1985, Oligocene paleogeography in the southern Denver Basin in Flores, R.M. And Kaplan, S.S., eds., Cenozoic Paleogeography of the West-Central United States, Rocky Mountain Section, Society for Economic Paleontology and Mineralogy, p. 277–292.

Nichols, D.J., 2003, Palynostratigraphic framework for age determination and correlation of the nonmarine lower Cenozoic of the Rocky Mountains and Great Plains region in Raynolds, R.G., and Flores, R.M., eds., Cenozoic systems of the Rocky Mountain region: Rocky Mountain section, Society of Economic Paleontologists and Mineralogists, p. 107–134.

Nichols, D.J., and Fleming, R.F., 2002, Palynology and palynostratigraphy of Maastrichtian, Paleocene, and Eocene strata in the Denver Basin, Colorado: Rocky Mountain Geology, v.37, no. 2, p. 135–163.

Raynolds, R.G., 1997, Synorogenic and post-orogenic strata in the central Front Range, Colorado in Bolyard, D.W., and Sonnenberg, S.A., eds., Geologic History of the Colorado Front Range: Rocky Mountain Association of Geologists Field Trip Guide, p. 43–47.

Raynolds, R.G., 2002, Upper Cretaceous and Tertiary stratigraphy of the Denver Basin, Colorado: Rocky Mountain Geology, v. 37, p. 111–134.

Raynolds, R.G., and K.R. Johnson, 2003, Synopsis of the Stratigraphy and paleontology of the uppermost Cretaceous and lower Tertiary strata in the Denver Basin, Colorado: Rocky Mountain Geology, v. 38, no. 1, p. 171–181.

Richardson, G.B., 1915, Castle Rock folio, Colorado: U.S. Geological Survey Geologic Atlas Folio 198, 19 p.

Rollinson, H.R., 1993, Using geochemical data, evaluation, presentation, interpretation: Longman, Harlow, UK, 352p.

Scott, G.R., 1962, Geology of the Littleton quadrangle, Jefferson, Douglas, and Arapahoe Counties, Colorado: U. S. Geological Survey Bulletin 1121-L, 53 p., scale 1:24,000.

Scott, G.R., 1963a, Quaternary geology and geomorphic history of the Kassler quadrangle, Colorado: U.S. Geological Survey Professional Paper 421-A, p. 1-71, scale 1:24,000.

Scott, G.R., 1963b, Bedrock geology of the Kassler quadrangle, Colorado: U.S. Geological Survey Professional Paper 421-B, p. 71–125, scale 1:24,000.

Scott, G.R., 1972, Geologic map of the Morrison quadrangle, Jefferson County, Colorado: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-790-A, 1:24,000 scale.

Scott, G.R., and Wobus, R.A., 1973, Reconnaissance geologic map of Colorado Springs and vicinity, Colorado: U.S. Geological Survey Miscellaneous Field Studies Map MF-482, scale 1:62,500.

Smith, J.H., 1964, Geology of the sedimentary rocks of the Morrison Quadrangle, Colorado: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-428, 1:24,000 scale.

Soister, P.E., 1968, Geologic map of the Corral Bluffs quadrangle, El Paso County, Colorado: U.S. Geological Survey Geological Quadrangle Map GQ-783, scale 1:24,000.

Soister, P.E., and Tschudy, R.H. 1978, Eocene rocks in Denver Basin, in Pruit, J.D., and Coffin, P.E., eds., Energy Resources of the Denver Basin: Rocky Mountain association of Geologists 1978 Symposium, p.231–235.

Temple, J., Madole, R., Keller, J., and Martin, D., 2007, Geologic map of the Mount Deception quadrangle, Teller and El Paso Counties, Colorado: Colorado Geological Survey Open-File Report 07-07. scale 1:24,000.

Temple, J., Busacca, A., Sicard, K., and Mendel, D., 2008, Geologic map of the Dakan Mountain quadrangle, Douglas, Teller, and El Paso Counties, Colorado: Colorado Geological Survey Open-File Report 08-16. Scale 1:24,000.

Thorson, J.P., 2003a, Geologic map of the Greenland quadrangle, El Paso and Douglas Counties, Colorado: Colorado Geological Survey Open-File Report 03-9. scale 1:24,000.

Thorson, J.P., 2003b, Geologic map of the Black Forest quadrangle, El Paso County, Colorado: Colorado Geological Survey Open-File Report 03-0. scale 1:24,000.

Thorson, J.P., 2004a, Geologic map of the Castle Rock South quadrangle, Douglas County, Colorado: Colorado Geological Survey Open-File Report 04-05. scale 1:24,000.

Thorson, J.P., 2004b, Geologic map of the Cherry Valley School quadrangle, Douglas, El Paso, and Elbert Counties, Colorado: Colorado Geological Survey Open-File Report 04-06. scale 1:24,000.

Thorson, J.P., 2005a, Geologic map of the Castle Rock North quadrangle, Douglas County, Colorado: Colorado Geological Survey Open-File Report 05-0. scale 1:24,000.

Thorson, J.P., 2006, Geologic map of the Russellville Gulch quadrangle, Douglas and Elbert Counties, Colorado: Colorado Geological Survey Open-File Report 06-08, scale 1:24,000.

Thorson, J.P., 2007a, Geologic map of the Ponderosa Park quadrangle, Douglas and Elbert Counties, Colorado: Colorado Geological Survey Open-File Report 07-04, scale 1:24,000.

Thorson, J.P. 2007b, Provenance and geochemistry of Laramide volcanic pebbles in the Denver Basin: Geological Society of America Abstracts with Programs, v.39, no.6, p. 26.

Thorson, J.P., Carroll, C.J., and Morgan, M.L., 2001, Geologic map of the Pikeview quadrangle, El Paso County, Colorado: Colorado Geological Survey Open-File Report 01-03, scale 1:24,000.

Thorson, J.P., and Madole, R.F., 2002, Geologic map of the Monument quadrangle, El Paso County, Colorado: Colorado Geological Survey Open-File Report 02-04, scale 1:24,000.

Thorson, J.P., Temple, J., Busacca, A., and Berg, W., 2008, Geologic map of the Larkspur quadrangle, Douglas and El Paso Counties, Colorado: Colorado Geological Survey Open-File Report 08-17, scale 1:24,000.

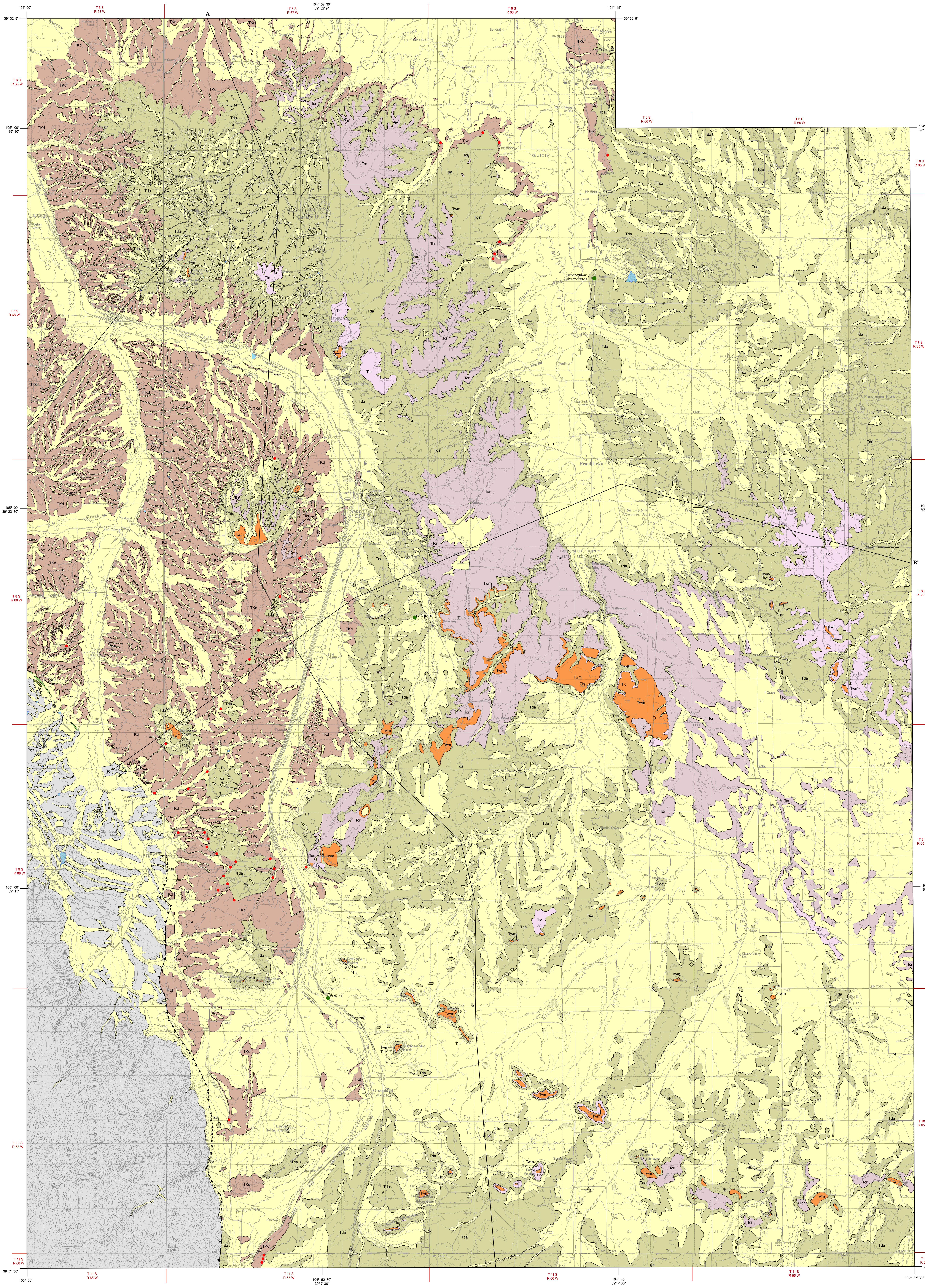
Trimble, D.E., and Machette, M.N., 1979a, Geological map of the Colorado Springs-Castle Rock area, Front Range urban corridor, Colorado: U.S. Geological Survey Miscellaneous Investigations Series I-857-F, scale 1:100,000.

Trimble, D.E., and Machette, M.N., 1979b, Geological map of the Greater Denver area, Front Range urban corridor, Colorado: U.S. Geological Survey Miscellaneous Investigations Series I-857-H, scale 1:100,000.

Varnes, D.J. and Scott, G.R., 1967, General and engineering geology of the United States Air Force Academy site, Colorado, with a section on ground water by W.E.D. Cardwell and E.D. Jenkins: U.S. Geological Survey Professional Paper 551, 93 p.

COLORADO GEOLOGICAL SURVEY
DEPARTMENT OF NATURAL RESOURCES
DENVER, COLORADO





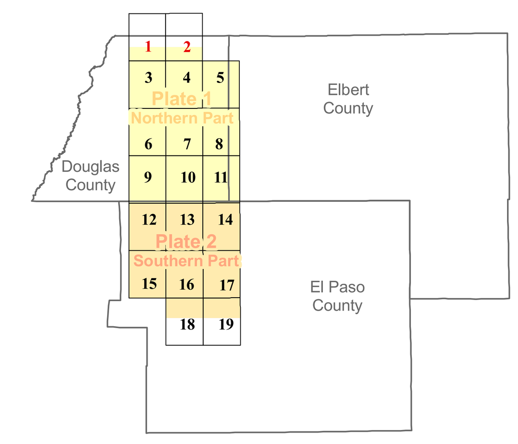

## LIST OF MAP UNITS

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

- younger — Younger units
- Tcr — Castle Rock Conglomerate (late Eocene)
- Twm — Wall Mountain Tuff (late Eocene)
- Tlc — Larkspur Conglomerate (Eocene)
- DENVER BASIN GROUP
  - Tda — Dawson Arkose (Paleocene and Eocene)
  - Tbs — Black Squirrel Formation (new name - Paleocene)
  - TKd — Denver Formation (Upper Cretaceous and Paleocene)
  - TKjc — Jimmy Camp Formation (new name - Upper Cretaceous and Paleocene)
  - TKpr — Pulpit Rock Formation (new name - Upper Cretaceous and Paleocene)
  - Kpv — Pikeview Formation (new name - Upper Cretaceous)
- Kl — Laramie Formation (Upper Cretaceous)
- Kfh — Fox Hills Sandstone (Upper Cretaceous)
- older — Older rocks

## MAP SYMBOLS

- Contact—Approximately located
- Fault—Dashed where approximately located; dotted where concealed; D, downthrown side
- Thrust fault—Dashed where approximately located; dotted where concealed; barbed teath are on overthrust block side of fault
- Approximate location of the Cretaceous-Tertiary boundary
- Water
- 5 — Strike and dip of inclined bedding—Showing direction and angle of dip
- Horizontal bedding
- 75 — Strike and dip of joint—Showing direction and angle of dip
- Vertical joint
- Sample location
- Fossil locality
- Paleosol exposure
- Abandoned and collapsed or reclaimed mine adit
- Quarry
- Water well
- Petroleum test well (drilled and abandoned)
- A——A' Alignment of cross sections



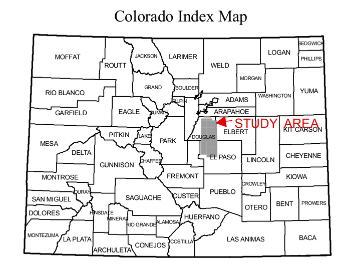

### 7.5' QUADRANGLES INCLUDED

- USGS Map
- CGS Map

### Quadrangle Name and 1:24,000 Scale Geologic Maps

1 Highlands Ranch; Maberry, J.O., and Lindvall, R.M., 1977, GQ-1413
2 Parker; Maberry, J.O., and Lindvall, R.M., 1972, I-770-A
3 Sedalia; Morgan, M.L., and others, 2005, OFR 05-06
4 Castle Rock North; Thorson, J.P., 2005, OFR 05-02
5 Ponderosa Park; Thorson, J.P., 2007, OFR 07-4
6 Dawson Butte; Morgan, M.L., and others, 2004, OFR 04-07
7 Castle Rock South; Thorson, J.P., 2004, OFR 04-5
8 Russellville Gulch; Thorson, J.P., 2006, OFR 06-08
9 Larkspur; Thorson, J.P., and others, 2008, OFR 08-17
10 Greenland; Thorson, J.P., and Himmelreich, J., 2003, OFR 03-09
11 Cherry Valley School; Thorson, J.P., 2004, OFR 04-06
12 Palmer Lake; Keller, J.W., and others, 2006, OFR 06-06
13 Monument; Thorson, J.P., and Madole, R.F., 2002, OFR 02-4
14 Black Forest; Thorson, J.P., 2003, OFR 03-6
15 Cascade; Morgan, M.L., and others, 2003, OFR 03-18
16 Pikeview; Thorson, J.P., and others, 2001, OFR 01-3
17 Falcon NW; Madole, R.F., 2003, OFR 03-8
18 Colorado Springs; Carroll, C.J., and Crawford, T.A., 2000, OFR 00-3
19 Elsmere; Madole, R.F., and Thorson, J.P., 2002, OFR 02-2

Colorado Index Map




SCALE 1:50,000

0 12.5 25 50 75 100 125 Miles

0 65,000 130,000 260,000 390,000 520,000 Feet

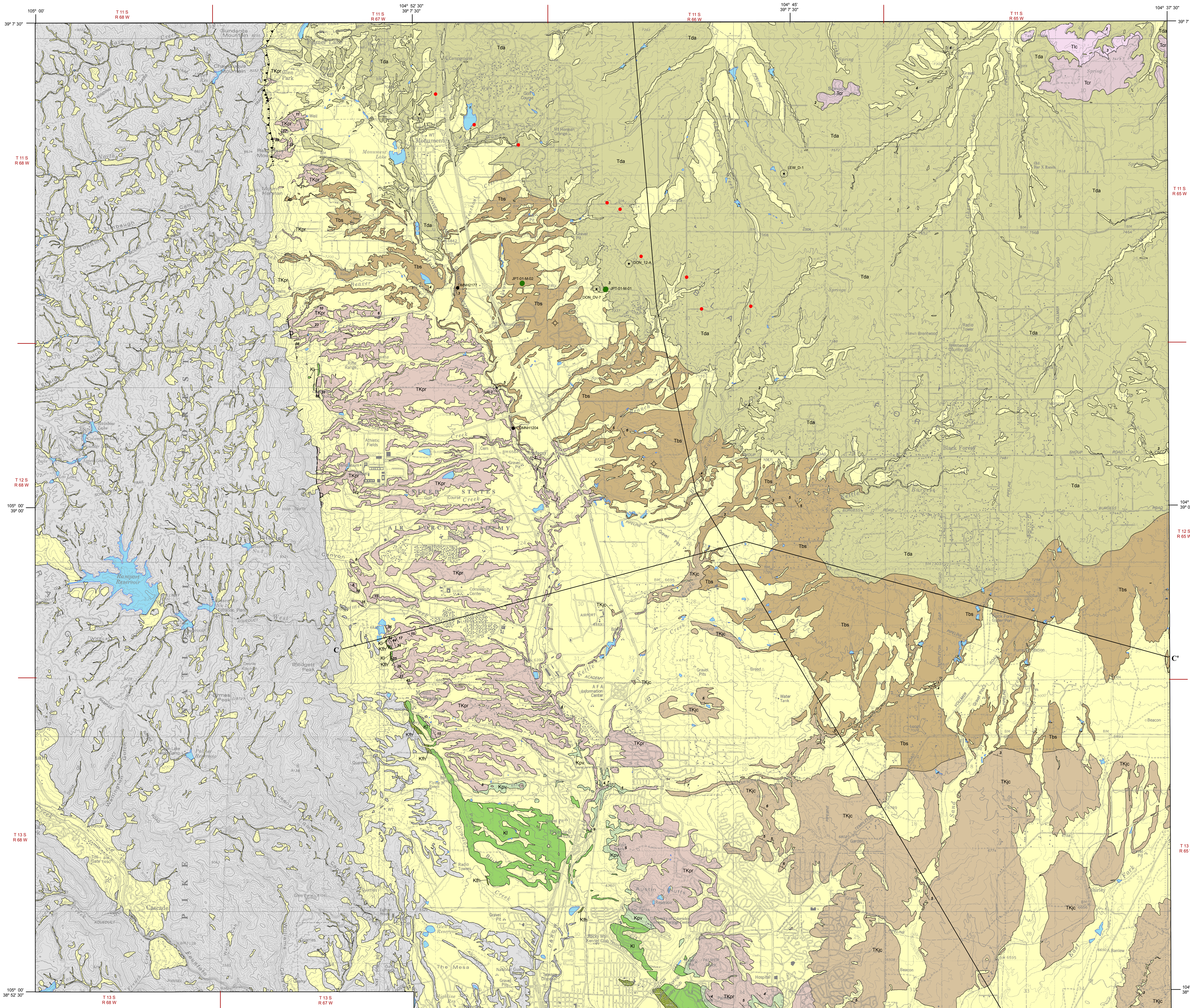
0 12.5 25 50 75 100 125 Kilometers

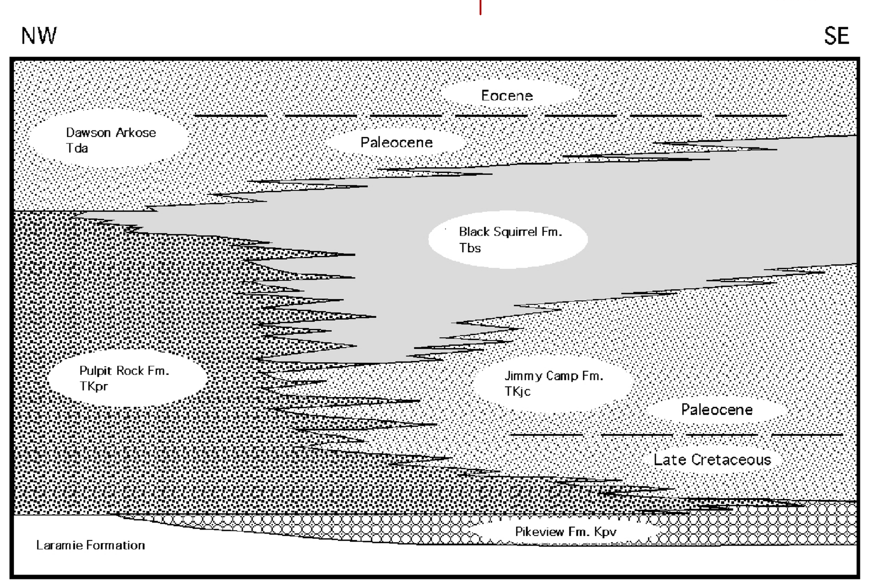
CONTOUR INTERVAL 40 and 80 FEET
DATUM IS MEAN SEA LEVEL

# GEOLOGY OF UPPER CRETACEOUS, PALEOCENE AND EOCENE STRATA IN THE SOUTHWESTERN DENVER BASIN, COLORADO (NORTHERN PART)

Jon P. Thorson
2011

John W. Hickenlooper, Governor
State of Colorado
Mike King, Executive Director
Department of Natural Resources
Vincent Matthews
State Geologist and Director
Colorado Geological Survey




Facies relationships between members of the Denver Basin Group across the Cascade, Pikeview, Falcon NW and Elsmere quadrangles.

## LIST OF MAP UNITS

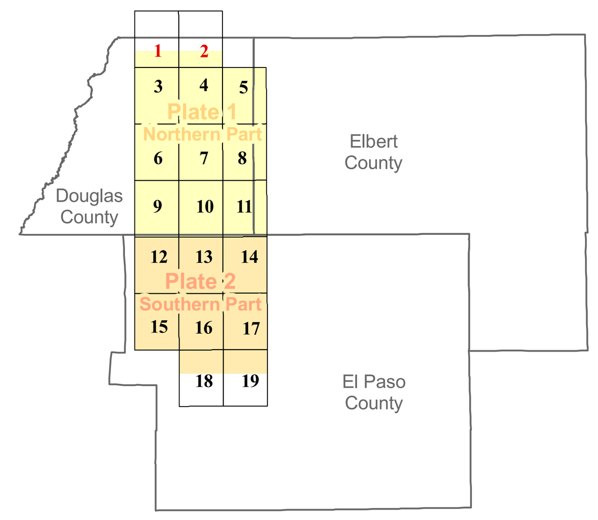
The complete description of map units and references are in the accompanying booklet

| | |
| --- | --- |
| younger | Younger units |
| Tcr | Castle Rock Conglomerate (late Eocene) |
| Twm | Wall Mountain Tuff (late Eocene) |
| Tlc | Larkspur Conglomerate (Eocene) |
| Tda | Dawson Arkose (Paleocene and Eocene) |
| Tbs | Black Squirrel Formation (new name - Paleocene) |
| Tkd | Denver Formation (Upper Cretaceous and Paleocene) |
| TKjc | Jimmy Camp Formation (new name - Upper Cretaceous and Paleocene) |
| TKpr | Pulpit Rock Formation (new name - Upper Cretaceous and Paleocene) |
| Kpv | Pikeview Formation (new name - Upper Cretaceous) |
| Kl | Laramie Formation (Upper Cretaceous) |
| Kfh | Fox Hills Sandstone (Upper Cretaceous) |
| older | Older rocks |

DENVER BASIN GROUP (Tda, Tbs, Tkd, TKjc, TKpr, Kpv)

## MAP SYMBOLS

- Contact—Approximately located
- Fault—Dashed where approximately located; dotted where concealed; D, downthrown side
- Thrust fault—Dashed where approximately located; dotted where concealed; barbed teath are on overthrust block side of fault
- Approximate location of the Cretaceous-Tertiary boundary
- Water
- Strike and dip of inclined bedding—Showing direction and angle of dip
- Horizontal bedding
- Strike and dip of joint—Showing direction and angle of dip
- Vertical joint
- Sample location
- Fossil locality
- Paleosol exposure
- Abandoned and collapsed or reclaimed mine adit
- Quarry
- Water well
- Petroleum test well (drilled and abandoned)
- A——A' Alignment of cross sections



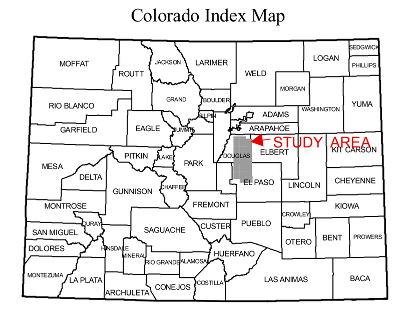

### 7.5' QUADRANGLES INCLUDED

- USGS Map
- CGS Map

### Quadrangle Name and 1:24,000 Scale Geologic Maps

1 Highlands Ranch; Maberry, J.O., and Lindvall, R.M., 1977, GQ-1413
2 Parker; Maberry, J.O., and Lindvall, R.M., 1972, I-770-A
3 Sedalia; Morgan, M.L., and others, 2005, OFR 05-06
4 Castle Rock North; Thorson, J.P., 2005, OFR 05-02
5 Ponderosa Park; Thorson, J.P., 2007, OFR 07-4
6 Dawson Butte; Morgan, M.L., and others, 2004, OFR 04-07
7 Castle Rock South; Thorson, J.P., 2004, OFR 04-5
8 Russellville Gulch; Thorson, J.P., 2006, OFR 06-08
9 Larkspur; Thorson, J.P., and others, 2008, OFR 08-17
10 Greenland; Thorson, J.P., and Himmelreich, J., 2003, OFR 03-09
11 Cherry Valley School; Thorson, J.P., 2004, OFR 04-06
12 Palmer Lake; Keller, J.W., and others, 2006, OFR 06-06
13 Monument; Thorson, J.P., and Madole, R.F., 2002, OFR 02-4
14 Black Forest; Thorson, J.P., 2003, OFR 03-6
15 Cascade; Morgan, M.L., and others, 2003, OFR 03-18
16 Pikeview; Thorson, J.P., and others, 2001, OFR 01-3
17 Falcon NW; Madole, R.F., 2003, OFR 03-8
18 Colorado Springs; Carroll, C.J., and Crawford, T.A., 2000, OFR 00-3
19 Elsmere; Madole, R.F., and Thorson, J.P., 2002, OFR 02-2

Colorado Index Map




SCALE 1:50,000

0 0.5 1 2 3 4 5 Miles
0 2,625 5,250 10,500 15,750 21,000 Feet
0 0.45 0.9 1.8 2.7 3.6 4.5 Kilometers

CONTOUR INTERVAL 40 and 80 FEET
DATUM IS MEAN SEA LEVEL

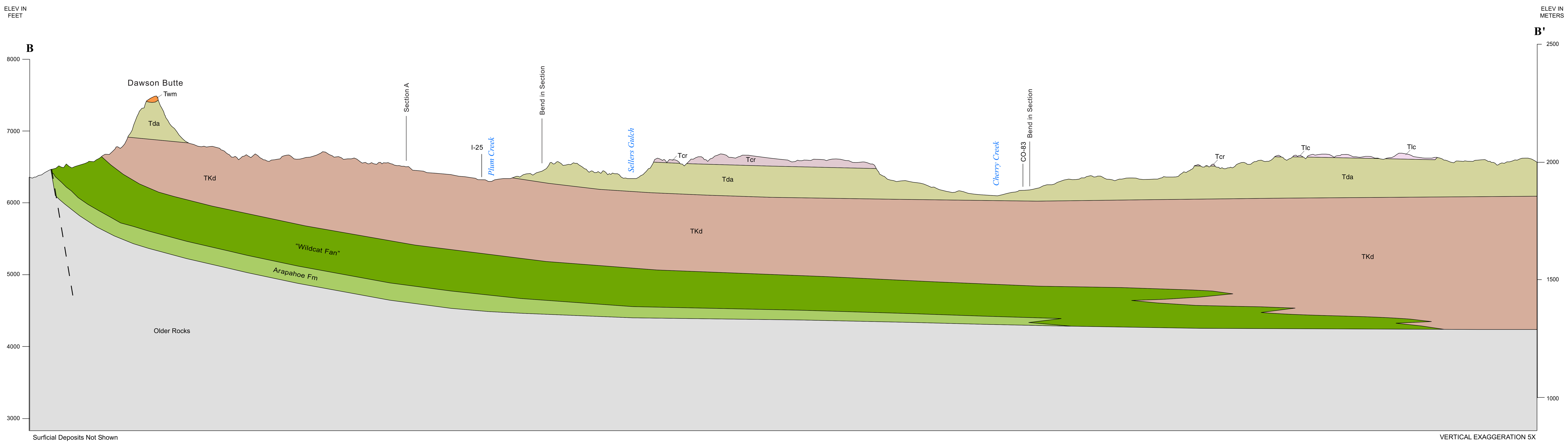
# GEOLOGY OF UPPER CRETACEOUS, PALEOCENE AND EOCENE STRATA IN THE SOUTHWESTERN DENVER BASIN, COLORADO (SOUTHERN PART)

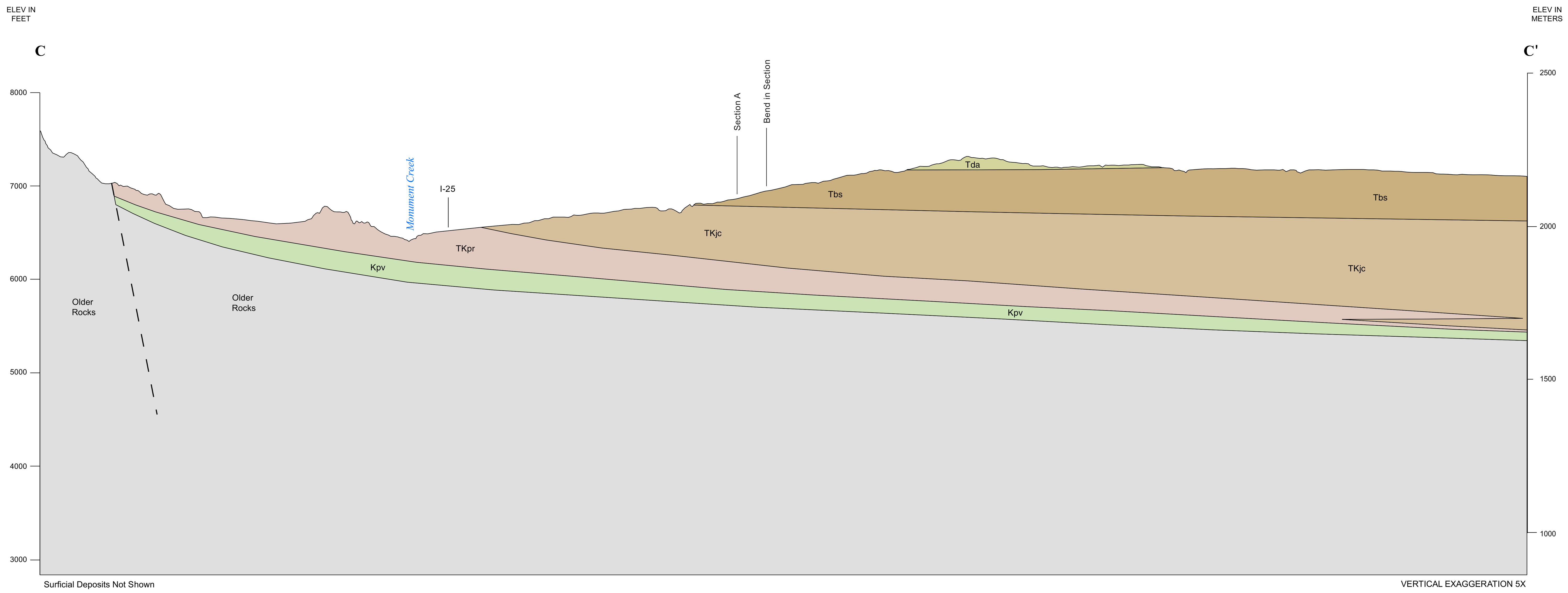
Jon P. Thorson
2011

John W. Hickenlooper, Governor
State of Colorado

Mike King, Executive Director
Department of Natural Resources

Vincent Matthews
State Geologist and Director
Colorado Geological Survey


# MAP COMPONENTS TO ACCOMPANY THE GEOLOGY OF UPPER CRETACEOUS, PALEOCENE AND EOCENE STRATA IN THE SOUTHWESTERN DENVER BASIN, COLORADO

Jon P. Thorson

2011

COLORADO
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