OPEN-FILE REPORT 05-2

Geologic Map of the Castle Rock North Quadrangle, Douglas County, Colorado

Bill Owens, Governor,
State of Colorado

Russell George, Executive Director,
Department of Natural Resources

Vincent Matthews,
State Geologist and Division Director,
Colorado Geological Survey

By Jon P. Thorson

Colorado Geological Survey
Department of Natural Resources
Denver, Colorado
2005

OPEN-FILE REPORT 05-2

Geologic Map of the Castle Rock North Quadrangle, Douglas County, Colorado

Bill Owens, Governor,
State of Colorado

COLORADO
DEPARTMENT OF NATURAL RESOURCES

Russell George, Executive Director,
Department of Natural Resources

COLORADO GEOLOGICAL SURVEY

Vincent Matthews,
State Geologist and Division Director,
Colorado Geological Survey

By Jon P. Thorson

This mapping project was funded jointly by the Colorado Geological Survey and the U.S. Geological Survey through the National Geologic Mapping Program under STATEMAP agreement No. 04HQPA003.

Colorado Geological Survey
Department of Natural Resources
Denver, Colorado
2005

FOREWORD

The purpose of Colorado Geological Survey Open File Report 05-2, *Geologic Map of the Castle Rock North Quadrangle, Douglas County, Colorado* is to describe the geologic setting and mineral resource potential of this 7.5-minute quadrangle located in central Colorado. Consulting Geologist Jon P. Thorson completed the field work on this project during the summer of 2004.

This mapping project was funded jointly by the U.S. Geological Survey through the STATEMAP component of the National Cooperative Geologic Mapping Program which is authorized by the National Geologic Mapping Act of 1997, Award number 04HQPA003, and the Colorado Geological Survey using the Colorado Department of Natural Resources Severance Tax Operational Funds. The CGS matching funds come from the Severance Tax paid on the production of natural gas, oil, coal, and metals.

Vince Matthews
State Geologist

ACKNOWLEDGMENTS

This mapping project was funded jointly by the Colorado Geological Survey and the U.S. Geological Survey through the National Geological Mapping Program. Many people have earned my thanks: Bob Raynolds, Kirk Johnson, and Vincent Matthews reviewed the map and text. Matt Morgan and Jason Wilson of the Colorado Geological Survey were valuable help in converting notes and field mapping on aerial photos into the geological map. Cheryl Brchan produced the final cartography and booklet. Jane Ciener was technical editor. Special thanks go to the landowners and developers who granted permission to enter their property.

CONTENTS

FIGURES

INTRODUCTION

The Castle Rock North 7.5-minute quadrangle is located immediately north of Castle Rock, Colorado, in the southern part of the Colorado Piedmont section of the Great Plains. The quadrangle is located in the Cherry Creek and Plum Creek drainage basins, which are tributary to the South Platte River. Geologic mapping of the Castle Rock North quadrangle was undertaken by the Colorado Geological Survey (CGS) as part of the STATEMAP component of the National Cooperative Geologic Mapping Program. Geologic maps produced by the CGS through the STATEMAP program are intended as multi-purpose maps useful for land-use planning, geotechnical engineering, geologic hazards assessment, mineral resource development, and ground-water evaluation. Figure 1 shows the location of the Castle Rock North quadrangle and the status of geologic mapping of 7.5-minute quadrangles in the Castle Rock area.

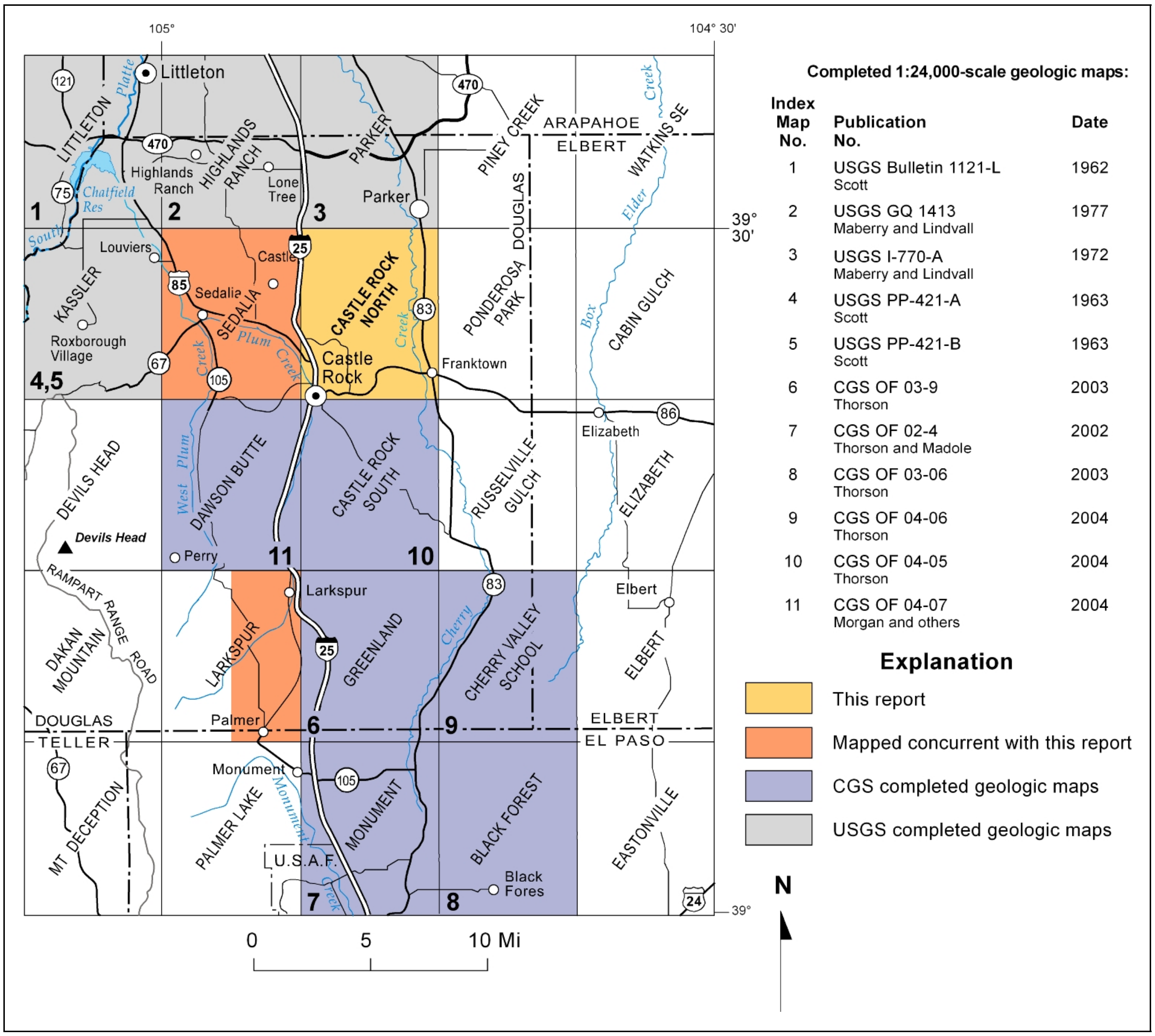

Figure 1a. Index map showing the location of the Castle Rock North quadrangle and adjacent 1:24,000 scale mapping by the U.S. Geological Survey and Colorado Geological Survey.

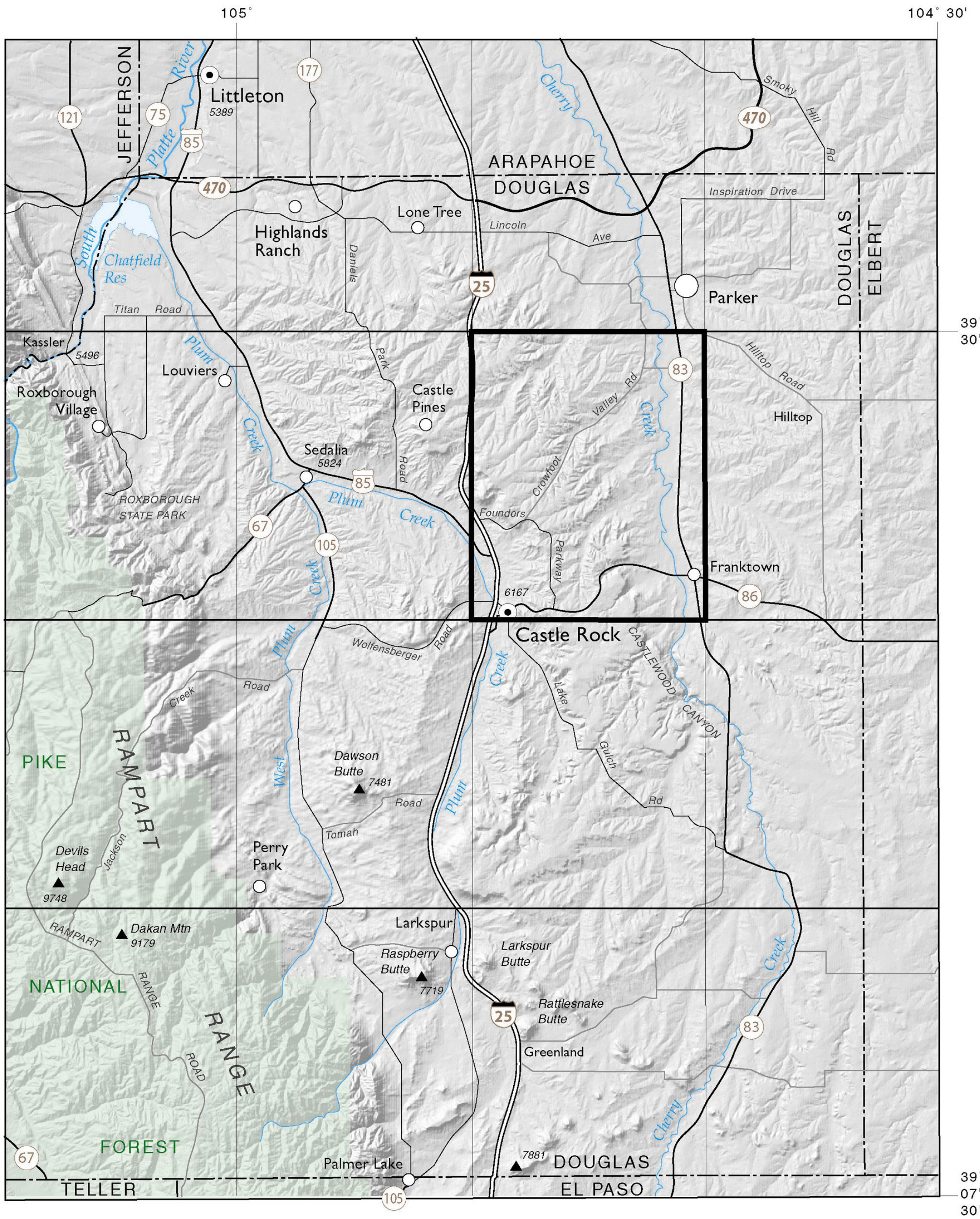

Figure 1b. Physiographic index map for the Castle Rock North quadrangle. Green overlay shows extent of Pike National Forest.

This map is based on prior published and unpublished geologic maps and reports, interpretation of aerial photography, and field mapping in 2004. The aerial photographs used are approximately 1:26,600 scale black and white photographs taken in 1971. The topographic base map for the Castle Rock North quadrangle was published in 1965 and updated by photo inspection in 1994. Consequently, some of the more recently constructed roads, buildings, and other human-made modifications of the landscape are not shown on the base map.

Previous geological mapping in the Castle Rock North area includes the work of Emmons and others (1896) and Richardson (1915). Trimble and Machette (1979) published a 1:100,000 scale regional geologic map of the Front Range urban corridor, which includes the Castle Rock North quadrangle. Bryant and others (1981) compiled a 1:250,000-scale map covering the Castle Rock North quadrangle. Maberry and Lindvall (1972, 1977) mapped the Parker and Highlands Ranch quadrangles, located immediately north and northwest, respectively, of the Castle Rock North quadrangle.

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

GEOLOGICAL SETTING

The Castle Rock North quadrangle is located near the western edge of an asymmetrical, oval-shaped, geological structural depression called the Denver Basin (Emmons and others, 1896). This structural basin lies immediately east of the Front Range and covers a large part of eastern Colorado north of Pueblo, southeastern Wyoming, and southwestern Nebraska.

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

Following the erosion of some of the upper part of the Dawson Formation, the conglomerate of Larkspur Butte (Thorson, 2003b) was deposited in a series of channels and broad valleys occupied by streams, which drained the newly rejuvenated mountains. In the western part of the Greenland quadrangle the conglomerate of Larkspur Butte was deposited in narrowly confined, steep-walled stream valleys. These valleys became broader towards the east as in the Cherry Valley School and Castle Rock South quadrangles. The same eastward widening is apparent in the Castle Rock North quadrangle.

The Wall Mountain Tuff, an ignimbrite or glowing hot volcanic ash flow, was erupted in the late Eocene and poured across the landscape. This ash flow blanketed the eroded surface of the Dawson Formation and valleys, which contained the conglomerate of Larkspur Butte. Because of its great heat the ash compacted into a viscous plastic which flowed for short distances before it cooled into welded tuff. Erosional remnants of the Wall Mountain Tuff overlie the Dawson Formation on two of the higher buttes in the western and north-central parts of the Castle Rock North quadrangle. The Castle Rock Conglomerate was deposited near the end of the Eocene in a broad sheet on an erosion surface that cuts across the upper Dawson Formation. Erosional remnants of the conglomerate of Larkspur Butte and Wall Mountain Tuff apparently stood at higher elevations at short distances above that surface.

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

AGE OF FORMATIONS

Dawson Formation. The upper part of the Dawson Formation spans the Cretaceous-Paleogene (K-P) boundary, but the exact location of the time boundary in most of the basin has not been identified. Kluth and Nelson (1988) reconfirmed the Late Cretaceous (late Maastrichtian) age for the upper part of the Dawson Formation on the U.S. Air Force Academy. In the Elsmere quadrangle, the K-P boundary has been approximately located about 370 feet above the base of the upper part of the Dawson Formation (Benson, 1998; Benson and Johnson, 1998; Johnson and Raynolds, 2001; Madole and Thorson, 2002 Johnson and others, 2003). Fossil leaf localities in the Monument quadrangle (Scotty's Palm, Denver Museum of Nature & Science, DMNH-1204, NE 1/4 SW 1/4 sec. 12, T. 12 S., R. 67 W., (Johnson, 2001, Johnson and others, 2003); and Baptist Road, Denver Museum of Nature & Science, DMNH-2177, NW 1/4 sec. 35. T. 11 S., R. 67 W., Johnson and Raynolds, 1998, Johnson and others, 2003) are Paleocene in age. An important early Paleocene rain forest fossil leaf locality, estimated to be 63.8 ± 0.3 mybp, (million years before present), is located in the Castle Rock North quadrangle in NE 1/4, SW 1/4, sec. 2, T. 8 S., R. 67 W, (Johnson and Ellis, 2002; Ellis and others, 2003; Johnson and others, 2003). This site is estimated to be 284 m above the K-P boundary on the basis of correlations with the Castle Pines cored well located in the adjacent Sedalia quadrangle (Ellis and others, 2003, Figure 2).

The rain forest fossil locality is estimated to lie just below the Denver Basin paleosol, a regional paleosol traced around the basin by Soister and Tschudy (1978) and proposed to mark the Paleocene-Eocene boundary. Recent work on this paleosol has recognized that it separates early Paleocene pollen zone P3 from late Paleocene pollen zone P6 (Nichols and Fleming, 2002) and lies just below the Paleocene-Eocene boundary. A prominent paleosol thought to be the Denver Basin paleosol was used as the boundary between Dawson facies units four and five in the Monument quadrangle (Thorson and Madole, 2002). Mapping of the Castle Rock South (Thorson, 2004a) and Castle Rock North quadrangles has shown that most of the local Dawson Formation lies above a well developed paleosol thought to be the Denver Basin paleosol and is therefore correlated with the Eocene TKda5 facies unit of the Monument quadrangle. However, Morgan and others (2004) have confirmed the observation that there are multiple paleosols developed in the Dawson Formation along the western edge of the Denver Basin (Thorson and Madole, 2002; Thorson, 2003a), so appropriate caution is advised in using the relation of a stratigraphic unit to any particular paleosol as an indication of age.

Conglomerate of Larkspur Butte. The conglomerate of Larkspur Butte (Tlc) is a newly recognized unit that underlies the late Eocene Wall Mountain Tuff on Larkspur Butte and on many of the high buttes in the Greenland (Thorson, 2004b), Black Forest (Thorson, 2003a) and Cherry Valley School (Thorson, 2004b) and Castle Rock South (Thorson, 2004a) quadrangles. This conglomerate is clearly of Eocene age; it lies between Eocene upper Dawson Formation and late Eocene Wall Mountain Tuff. It is of probable late Eocene age because a significant part of the Eocene epoch probably passed during the deposition, alteration, and erosion of the upper Dawson. And, a late Eocene age is indicated because the conglomerate of Larkspur Butte fills, or partially fills, paleovalleys that were present in the late Eocene and appear to have influenced the deposition of the late Eocene Wall Mountain Tuff.

Wall Mountain Tuff. 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 (Mcintosh and others, 1992; Mcintosh and Chapin, 1994). However, the age for the end of the Eocene is now recognized to be 33.7 mybp (Remane and others, 2002), so the Wall Mountain Tuff should now be considered to be late Eocene.

Castle Rock Conglomerate. The Castle Rock Conglomerate post-dates the Wall Mountain Tuff because the conglomerate contains clasts of the tuff. The Castle Rock Conglomerate also contains bones of Chadronian (late Eocene) titanotheres (K. R. Johnson, Denver Museum of Nature and Science, written commun., 2002) and so must be late Eocene in age, between 35.7 and 33.7 mybp.

DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSITS

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

af **Artificial fill (latest Holocene) —** Gravel, sand, silt, clay, and rock or concrete debris emplaced for constructing highways, railroads, and dams. This category includes rock quarry waste, on the edges of the top of the prominent butte near the west edge of the quadrangle in sec. 22, T. 7 S., R. 67 W. Thickness generally is between 5 and 50 ft.

ALLUVIAL DEPOSITS — Sand, silt, gravel, and clay transported and deposited by flowing water in channels or as unconfined runoff. The alluvial deposits in the Castle Rock North quadrangle are predominantly composed of quartz, feldspar, and granite fragments derived mostly from arkosic source materials in the Dawson Formation. Most of the fragments in the channel and flood-plain (Qa) and terrace (Qt1, Qt2, Qt3) deposits are subround coarse pebbles (less than 1.25 inches) or smaller grains. Occasional larger pebbles and small cobbles (up to about 4 inches) of well rounded light-colored quartz and subangular to subround yellow-brown chert, and rare larger cobbles and small boulders of round to subround dark-pink to light-red Pikes Peak Granite, found in the channel, flood-plain, and terrace deposits cannot have been derived from the Dawson. These clasts appear to be recycled from either the older surficial deposits, the conglomerate of Larkspur Butte, or from the Castle Rock Conglomerate. Large cobbles and small boulders of subround Dawson Formation arkose or angular to subangular brownish-gray welded tuff in the alluvial deposits were derived from local sources.

Part of the Castle Rock North quadrangle is mantled by older alluvial deposits of probable Pleistocene age (Qp1, Qp2). The relative age of these deposits has been interpreted from the slope, base level, and position in the landscape. These deposits have been grouped together as “older alluvium” because they represent higher elevations of the present drainage system. The youngest of these older alluvial deposits, Qp1, has surfaces which mimic the present drainage system but represent material deposited during a higher base level of the drainage than present. The position of the oldest alluvial deposits, Qp2, at higher elevation positions in the landscape than Qp1, suggests that these deposits may be the remnants of older drainage systems.

Qa **Channel and flood-plain alluvium (late Holocene) —** Pale-brown to brown sand, gravel, silt, and minor clay underlying narrow flood plains, stream channels, and, locally, low terraces flanking flood plains. Unit is generally coarser, lighter in color, and more poorly sorted than unit Qt1. In many places, the unit is so young that plant roots have scarcely disturbed or destroyed stratification that extends nearly to the ground surface. Typically soil has not developed. Unit is subject to frequent flooding. Estimated thickness is 3-7 ft.

Qt1 **Terrace alluvium one (Holocene and late Pleistocene) —** Pale-brown and brown to grayish-brown beds of sand, silty fine sand, sandy silt, clayey silt, and gravel. Generally, stratification is weakly expressed, and texture and composition vary along the valley axis. The upper surface of the unit is 3-10 ft higher than some of the larger streams but is only about 2-5 ft higher than the smaller streams of the area. Infrequent large floods may inundate Qt1 in places. The unit correlates with the Post-Piney Creek Alluvium of Maberry and Lindvall (1972). Thickness is estimated to be 5-15 ft.

Qt2 **Terrace alluvium two (late Pleistocene) —** Very pale-brown to dark grayish-brown, extremely poorly sorted sand and subordinate amounts of gravel. The unit correlates with the Piney Creek Alluvium of Maberry and Lindvall (1972). The upper surface of the unit is typically 5-15 ft higher than the larger streams. Thickness is 5-20 ft.

Qt3 **Terrace alluvium three (late middle Pleistocene) —** Chiefly pale-brown to light grayish-brown, extremely poorly sorted sand, gravel, and cobbly or bouldery gravel that underlies terrace remnants along the larger streams of the area. The upper surface of the unit is 20-40 ft higher than the drainages. The unit may correspond to Broadway Alluvium of Maberry and Lindvall (1972). Estimated thickness is 5-30 ft.

Qsw **Sheetwash (Holocene and late Pleistocene) —** Typically, light grayish-brown, pale-brown, to brown, extremely poorly sorted sand, silty and clayey sand, and minor amounts of gravel including some cobbles and small boulders. Unit consists chiefly of material transported on moderate slopes by sheet flow but also includes some sediment delivered by runoff in rills and minor gullies. The abundance of sand-size grains and pebbles in this unit make it a gruss-like deposit. The unit has been largely derived from disintegration of the Dawson Formation, but a smaller amount may have been derived from the older alluvial deposits. Estimated thickness is 3-20 ft.

Qaf **Alluvial-fan deposits (Holocene and late Pleistocene)** — Typically, light grayish-brown, pale-brown, to brown very poorly sorted sand, silt, and minor gravel deposited by tributary streams on fans at the edges of valley floors. The unit is composed of material that is essentially the same as the sheetwash deposits (Qsw) and was probably largely deposited by sheet-flow processes, although it may contain also some material transported by debris-flow and mud-flow processes. The geomorphic form of these alluvial fan deposits allows them to be mapped separately. Estimated thickness is 3-20 ft.

Qp1 **Older alluvium one (late Pleistocene) —** Chiefly light-brown to light reddish-brown, extremely poorly sorted sand and coarse gravel, which, in places, includes boulders as well as pebbles and cobbles. The unit may have cobbly and bouldery layers with angular to subround fragments of Wall Mountain Tuff, subrounded clasts of Dawson Formation arkose, and in places abundant well rounded cobbles and small bounders of granite, gneiss, and quartzite weathered out of the Castle Rock Conglomerate. This unit appears to correlate with the Slocum Alluvium of Maberry and Lindvall (1972) but may include some material that they would have mapped as Louviers Alluvium at lower elevations. Unit Qp1 is poorly exposed; estimated thickness may be a great as 60 ft.

Qp2 **Older alluvium two (early? to middle Pleistocene) —** This deposit is composed of light-brown sand and fine gravel that appears to be derived from the Dawson Formation, plus cobbles and small boulders of Dawson Formation arkose, Wall Mountain Tuff, and well rounded pebbles or cobbles of granite, gneiss, and quartzite from the conglomerate of Larkspur Butte or Castle Rock Conglomerate. Qp2 is the highest alluvial deposit in the Castle Rock North quadrangle and, therefore, probably the oldest. Qp2 slopes generally toward the north. Unit is about 5 to 40 ft thick.

MASS-WASTING DEPOSITS — Earth materials that were translocated downslope under the influence of gravity. Colluvium deposits are the principal products of mass wasting in the Castle Rock North quadrangle. Colluvium, as used here, adheres in most respects to Hilgard's (1892) definition. According to Hilgard, the principal attributes of colluvium are that it (1) was derived locally and transported only short distances, (2) may contain clasts of any size, (3) has no structures indicative of sedimentation or stratification by water flowing in channels, and (4) has an areal distribution that bears no relation to channelized flow of water (Madole and Streufert, 2001). Hilgard's definition allows colluvium to include a minor amount of sheetwash alluvium.

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

BEDROCK DEPOSITS

Tcr **Castle Rock Conglomerate (late Eocene) —** The Castle Rock Conglomerate is a pebble, cobble, and boulder arkosic conglomerate composed dominantly of subround to round fragments of pink and gray granite and quartz with subordinate amounts of gneissic metamorphic rocks, quartzite, red sandstone, 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 subangular cobble- 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. 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 (33.7 my; Remane and others, 2002) 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 up to 100 feet in parts of the quadrangle.

The Castle Rock Conglomerate was deposited as a large sheet on an erosion surface cut across the top of the upper Dawson Formation, conglomerate of Larkspur Butte, and Wall Mountain Tuff. This surface slopes gently to the north and northeast from over 6500 feet in the southwest corner of the quadrangle to below 6200 feet in sec. 32. T. 6 S., R. 66

W.   Along the present drainage divide from the NE 1/4 sec. 15. T. 7 S., R. 67 W., to NE1/4 sec. 36. T. 7 S., R. 67 W. (east of the Plum Creek valley north of the town of Castle Rock), erosional remnants of the conglomerate of Larkspur Butte and Wall Mountain Tuff are preserved on a ridge which must have been present during the deposition of the Castle Rock Conglomerate. Here these older units occur at higher elevations than the Castle Rock Conglomerate depositional surface. The eastern edge of the sheet of Castle Rock Conglomerate in the Castle Rock North quadrangle occurs at a lower elevation than the ridges east of Cherry Creek, in the adjacent Ponderosa Park and Piney Creek quadrangles, where no Castle Rock Conglomerate was mapped by Trimble and Machette (1979b). Thus it appears that the Castle Rock Conglomerate may be the remains of an ancient paleo-valley filling deposit trending north-northwest and roughly paralleling the present Cherry Creek Valley.

The Castle Rock Conglomerate is variably permeable, in some places well drained and in others supporting local ephemeral ponds, but has good foundation characteristics. Excavation may be difficult, even though the unit is friable and easily eroded on weathered outcrops. Rock fall from cliffs at the edges of plateaus of this unit poses a possible slope-stability hazard in some areas, especially where the unit rests on easily erodable sandstone or sandy mudstone beds in the Dawson Formation.

Twm **Wall Mountain Tuff (late Eocene) —** The Wall Mountain Tuff is a moderately to densely welded tuff of rhyolitic composition (Izett and others, 1969; Epis and Chapin, 1974). It is generally light- to medium-brown when fresh but is occasionally medium-gray in a few of the more densely welded outcrops. On weathering the tuff may be light brown, lavender, pink, reddish brown, or maroon. The fine-grained groundmass usually contains small phenocrysts of biotite and sanidine, and occasionally near the base may contain quartz grains and small arkose fragments ripped up from the underlying strata. The Wall Mountain Tuff was emplaced in the Castle Rock area as an ash-flow that was hot enough that the ash compacted and welded into a viscous plastic-like consistency after emplacement. In places, the welded ash flowed and developed flow banding before cooling and solidifying. The Wall Mountain Tuff has been dated as about 36.7 million years in age by McIntosh and others (1992) and McIntosh and Chapin (1994).   The Wall Mountain ash-flow was erupted from an unidentified location west of the upper Arkansas River valley between Salida and Buena Vista (Epis and Chapin, 1974).

The Wall Mountain Tuff is about 40 feet thick in the larger of the two erosional remnants in the quadrangle (east edge of sec. 22. T. 7 S., R. 67 W.) where it rests on an older deposit of conglomerate of Larkspur Butte at an elevation of about 6680 feet. The other remnant (center sec. 6, T. 7 S., R. 66 W.) has its base resting on Dawson facies unit TKda5 at an elevation of about 6350 feet, indicating a northeast dip of about 80 feet per mile.

Tlc **Conglomerate of Larkspur Butte (late? Eocene) —** The conglomerate of Larkspur Butte is a brown, pinkish-brown, or pink arkosic conglomerate composed predominantly of pebbles and cobbles of pink granite or pink feldspar in a coarse sand-size to small-pebble matrix of quartz and pink feldspar.   Clasts of gray or white quartz are common; less abundant are clasts of gneissic metamorphic rocks, quartzite, red sandstone, and chert; clasts are subround to round. Clasts of eroded Dawson Formation arkose are common near the base of the unit.

The conglomerate of Larkspur Butte is distinguished from the underlying Dawson Formation by its coarser grain size, pinkish color tones, dominance of pink granite and unbleached pink feldspar grains, and lack of clay in the matrix material. The uppermost strata of the Dawson are generally very light colored (white, cream, light greenish-gray) because most of the feldspar in the Dawson Formation is bleached and essentially all of the macroscopic pores of the Dawson beds are filled with light colored clay. The bleaching and clay-filling in the Dawson suggests a prolonged period of weathering and/or diagenetic alteration of the Dawson before deposition of the conglomerate of Larkspur Butte. The conglomerate of Larkspur Butte is similar in appearance to the Castle Rock Conglomerate although the latter generally lacks pink tones and is light gray in color. The principal distinguishing characteristic is the fragments of Wall Mountain Tuff in the Castle Rock Conglomerate. In the absence of tuff fragments, the two late-Eocene conglomerates may be very hard to distinguish. The conglomerate of Larkspur Butte is up to 80 feet thick in the quadrangle.

The conglomerate of Larkspur Butte is generally permeable, well drained, and has good foundation characteristics. Excavation may be difficult, even though the some of the conglomerate is friable and easily eroded on weathered outcrops. Rock fall from cliffs in this unit poses a possible slope-stability hazard in some areas. Large blocks of this conglomerate separate and creep away from cliff edges along joint planes and slide or topple down slope where the unit is undermined by erosion of softer underlying Dawson Formation.

Dawson Formation (Upper Cretaceous to Eocene) — The Dawson Formation is divided into upper and lower parts in the Colorado Springs area (Thorson and others, 2001, Thorson and Madole, 2002). The lower part is entirely Upper Cretaceous in age and composed almost exclusively of andesitic debris. The upper part of the Dawson Formation is a mixture of andesitic and arkosic material deposited during the Late Cretaceous and early Tertiary. The upper part of the Dawson Formation is divided into facies unit one (TKda1), facies unit two (TKda2), facies unit three (TKda3), facies unit four (TKda4), and facies unit five (TKda5). A sixth facies unit has been recognized locally in the Cherry Valley School (Thorson, 2004b) and Larkspur quadrangles (Thorson, 2005). These facies units are differentiated on the relative proportions of andesitic and arkosic material, on the thickness and style of coarse-grained bedding units, and on the relative proportion of fine-grained claystone and siltstone versus coarser-grained beds of sandstone, arkose, pebbly arkose, and pebble conglomerate. Only facies unit four (TKda4) and facies unit five (TKda5) are present in the Castle Rock North quadrangle.

In the Denver area, and extending into Castle Rock North quadrangle, the nomenclature for the comparable Upper Cretaceous to Eocene strata mapped as Dawson Formation in the Colorado Springs area, is quite variable. Maberry and Lindvall (1972, 1977) used Dawson Arkose and Denver Formation, with the Dawson Arkose younger than, and stratigraphically superior to, the Denver Formation. Trimble and Machette (1979b) changed terminology and used “Dawson and Arapahoe Formations” and “Denver

Formation" of comparable Paleocene to Upper Cretaceous age. Bryant and others (1981) used Arapahoe Formation and restricted this unit to Upper Cretaceous age, while Dawson Arkose and Denver Formation were retained. On the map of Bryant and others, the Dawson Arkose is designated as Eocene, Paleocene, and Upper Cretaceous, the Denver Formation is described as Paleocene and Upper Cretaceous, and the formations are shown as interfingering lateral equivalents of each other.

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

However, paleontological control is necessary for the recognition and application of the D1-D2 nomenclature. Recent mapping along the west side of the Denver Basin (Thorson and Madole, 2002; Thorson, 2003a, 2005; Morgan and others, 2004) has shown that there are multiple paleosol horizons in the Dawson Formation, and that no single paleosol exposure clearly defines the D1-D2 boundary without confirmation. None-the-less, facies unit TKda5 of this report appears to be consistently equivalent to Raynolds' D2 sequence.

Logs and samples from the Dawson in the abandoned petroleum test well in the Greenland quadrangle (sec 17, T. 10 S., R. 66 W.; F.G. Holl et al., #1 Greenland Cattle Co.), plus the thickness of Dawson exposed on the adjacent buttes above the collar of the well, indicate that the Dawson Formation is about 2750 feet thick.

TKda5 **Facies unit five (early to middle? Eocene) —** The TKda5 unit is dominated by very thick-bedded to massive, cross-bedded, light-colored arkoses, pebbly arkoses, and arkosic pebble conglomerate, but 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. Facies unit five also contains a few massive structureless beds interpreted to be mudflows and common beds of greenish-gray to olive-green sandy claystone. Facies unit five becomes finer grained towards the east and looses much of its distinctive thick-bedded character so that it becomes difficult to distinguish from facies unit four along the eastern edge of the quadrangle. Occasionally unit TKda5 contains thin, poorly developed, red, pink, and yellow-brown oxidized zones interbedded with, or developed within, the thick arkoses. Some of these oxidized zones have preserved mottling, burrows, and root structures that indicate their origin as paleosols; others are probably just the result of oxidation by groundwater. TKda5 is at least 400 ft thick in the quadrangle but the top of the unit has been removed by erosion. TKda5 appears to correlate with Raynolds' (2002) D2 sequence, with the Dawson Arkose of Mayberry and Lindvall (1972, 1977), but does not correlate specifically with any of the units used by Bryant and others, 1981).

TKda5 is generally permeable, well drained, and has good foundation characteristics. Excavation may be difficult even though the arkoses are friable and easily eroded on weathered outcrops. The massive mudflow beds can be well indurated and may require considerable effort to excavate. The clay content of the finer grained parts of the facies unit suggests that soils developed from the Dawson may have high swell factors. Rock fall from cliffs in facies unit five poses a possible slope-stability hazard in some areas. Facies unit five appears to be equivalent to the Dawson Arkose and/or Dawson aquifer in the Denver area (George VanSlyke, 2001, oral commun.).

TKda4 **Facies unit four (early Paleocene)** - Facies unit four is dominated by greenish-gray to light-gray sandy claystone and clayey sandstone but contains beds of white to light-tan, fine- to medium-grained, feldspathic cross-bedded friable sandstone similar to those in TKda5. The sandstones are poorly sorted, have high clay contents, and are commonly thin or medium bedded; wavy bedding and ripple cross-laminations are also common. Only the upper part of facies unit four (about 100 feet) is exposed in the quadrangle.

In the Monument quadrangle (Thorson and Madole, 2002), the Dawson Butte quadrangle (Morgan and others, 2004), and Castle Rock South quadrangle (Thorson, 2004a), the top of facies unit four is marked by a strongly developed paleosol that was traced around the Denver Basin by Soister and Tschudy (1978). This Denver Basin paleosol has been studied extensively by Farnham and Kraus (2002) and Nichols and Fleming, (2002), and 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 quadrangle in two clay pits (NW 1/4 sec. 35, T. 6 S., R. 66 W. and NE 1/4 sec. 8, T. 7 S., R. 66 W.) and in Newlin Gulch (SW 1/4 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 quadrangle during fieldwork but have proved to be ephemeral, being buried as frequently as they were exposed. In the northeast part of the quadrangle, the Denver Basin paleosol clearly marks the boundary between TKda4 and TKda5.

A poorly exposed paleosol, which may be the Denver Basin paleosol of Soister and Tschudy (1978), occurs at the foot of the west flank of Castle Rock (SE cor. sec. 2, T. 8 S., R. 67 W.) and in a roadcut along Interstate Highway 25 just west of the western edge of the quadrangle. The projected location of this paleosol should be just above the Castle Rock rainforest leaf fossil locality (Ellis and others, 2003) of Paleocene age. The projected location of this paleosol is used as the boundary between TKda4 and TKda5 in the southwest part of the quadrangle. In this case a note of caution must be sounded; in the Dawson Butte quadrangle (Morgan and others, 2004), Black Forest quadrangle, (Thorson, 2003a), and Monument quadrangle (Thorson and Madole, 2002), multiple paleosol horizons have been documented. Only one of these can be the "Denver Basin Paleosol" of Soister and Tschudy (1978), so paleontological confirmation is necessary before confidently using a paleosol occurrence as a distinctive time marker.

TKda4 appears to correlate with the top of Raynolds' (2002) D1 sequence, with the Denver Formation of Mayberry and Lindvall (1972, 1977), but does not correlate specifically with any of the units used by Bryant and others, (1981). Neither the base of TKda4 nor the lower facies units of the Dawson Formation are exposed in the Castle Rock North quadrangle.

Facies unit four is quite variable in permeability but usually well drained at the surface. It appears to have good foundation characteristics, but the greenish-gray and olive-green claystone beds have high swell factors, being apparently rich in montmorillonitic clays. Soils developed from this unit may have very high swelling characteristics. It is common practice in subdivision construction in the quadrangle to excavate areas of TKda4 around proposed foundations and replace the material with sandy fill of lower swell factor and better drainage permeability. However, caution is advised to make sure that appropriate measures have been taken to accommodate swelling soils and heaving bedrock, particularly in areas of TKda4.

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

STRUCTURAL GEOLOGY

The structural geology of the Castle Rock North quadrangle is not complex. Most of the Dawson strata are flat lying or very gently dipping. Few strike and dip symbols are shown on the map. Measurement of strike and dip in the Dawson Formation is difficult and questionable because of the coarse-grained, lenticular and cross-bedded character of most of the beds and because of poor exposures. Bedding surfaces and cross-bed orientation from these beds were inclined at deposition and are unlikely to be representative of the strike and dip of the whole unit. Strike and dip measurements shown on the map were made on thin-bedded, fine-grained strata that were more likely deposited in a horizontal orientation.

MINERAL RESOURCES

Sand, gravel, and clay are the most significant potential mineral resources in the Castle Rock North quadrangle. No test wells for oil and gas occur. No radioactive mineral resources are known in the quadrangle. One small area has been exploited, apparently for gold.

SAND AND GRAVEL

Sand and gravel are widely available in the quadrangle from surficial deposits derived mostly from erosion of the Dawson Formation, but there is little indication that these resources are currently being exploited from the quadrangle. The gravel pit shown on the map in sec. 34, T. 7 S., R. 66 W. is inactive and has been recontoured and reclaimed. The gravel pit shown on the map in sec. 3, T. 8 S., R. 66 W. was active during the field work in the summer of 2004.

CLAY

Clay, apparently mostly for brick manufacture, has been mined from pits in the quadrangle in sec. 26 and 35, 6 S., R. 66 W., and in sec. 3 and 8, 7 S., R. 66 W. All of these pits are located in areas of strongly developed paleosol weathering at the top of the Dawson Formation TKda4 unit. The deep weathering of the arkosic Dawson Formation lithologies in this horizon appears to make acceptable clay. The clay pits in W 1/2, NW 1/4, sec. 35, 6 S., R. 66 W. and NW 1/4, NE 1/4, sec. 8, 7 S., R. 66 W. were actively being exploited during the summer of 2004; the rest are in various states of abandonment or reclamation.

BUILDING STONE

The Wall Mountain Tuff has been extensively quarried for building stone in the Castle Rock area for over a century. One of these quarries operated sometime in the past on the top of the prominent butte that straddles the boundary between sec. 22 and 23, T. 7 S., R. 67 W. These quarries, although abandoned, are still open; the sites and waste piles are only partially overgrown with vegetation.

OIL AND GAS

The Colorado Oil and Gas Commission has no completion records for petroleum test wells in the Castle Rock North quadrangle. The nearest oil production is about 25 miles northeast of the quadrangle, north of Kiowa in Elbert County.

GOLD

A small area in Newlin Gulch (on the boundary between sec. 36, 6 S., R. 67 W., and sec. 31, 6 S., R. 66 W.), about 600 feet by 300 feet in size, appears to be an old abandoned placer gold mine. In this area unit Qt3 forms a bench about 20 to 30 feet above the stream level. Within this disturbed area, gravels have been mined and washed for gold, leaving large piles of oversize stream boulders too large for the processing equipment. Although no gold has been confirmed from the site, abandoned rusty machinery on the site, and the style of disturbance, clearly indicate that the disturbance was created by washing gravel to process alluvial gold. The size of the disturbed area suggests that mining may have been at least initially successful. No other remaining evidence of placer mining was found in the quadrangle.

Directly up slope, about 1200 feet west-southwest of the placer mine described above, two small caved adit (tunnel) sites and mine dumps mark attempts to explore or mine the Dawson Formation TKda5 unit. The larger of the two adits has completely collapsed; the smaller is partially open although greatly restricted by collapse. On the basis of the dump size, the larger adit must have been driven about 50 feet into the bedrock. These adits were probably driven by prospectors searching for a bedrock source of the nearby alluvial gold.

Vanderwilt, (1947) contains brief descriptions of gold placers on Newlin Gulch, Cherry Creek, Lemon Gulch, and Happy Canyon, at unspecific locations that might be in the Castle Rock North quadrangle. According to Parker (1974) the Newlin Creek placers are among the very oldest known in Colorado, probably discovered in 1858, although specific clear records do not exist. The discovery of alluvial gold in the Cherry Creek drainage, including Russellville Gulch and probably Newlin Gulch, was the spark that created the Pikes Peak Gold Rush of 1859, which began the first serious influx of settlers into Colorado. Parker describes several attempts to evaluate and mine the Newlin Gulch placers, most of which failed because of lack of consistent water flow in the stream. All of the attempts at mining in Newlin Gulch and Cherry Creek in the Castle Rock north quadrangle, other than those described above, have been erased by later floods and erosion along the drainages. The source of the gold in Newlin Gulch and several other local occurrences is judged by Parker (1974) and Desbrough and others (1970) to be reconcentrations from the Castle Rock Conglomerate.

WATER RESOURCES

Water resources in the Castle Rock North quadrangle are contained either in shallow groundwater aquifers in surficial alluvial deposits along the major stream drainages, largely the terrace deposits Qt1, Qt2, and Qt3, or in deeper groundwater aquifers of the Denver Basin (Robson, 1987, 1989). This basin contains four major aquifers: the Dawson, Denver, Arapahoe and Laramie-Fox Hills, listed from the top down. Drill depths anticipated to completely test the four deep aquifers in the Castle Rock North quadrangle are approximately 1000, 2000, 2500, and 3000 ft., respectively (Robson, 1987). A comprehensive review of the geology and issues associated with ground water supply in the Castle Rock North quadrangle is well beyond the scope of this report. The interested reader is referred to Topper and others (2003), and Raynolds and Reynolds, (2004), as recent reviews of the subject.

GEOLOGIC HAZARDS

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

REFERENCES CITED

Barclay, R.S., Johnson. K.R, Betterton, W.J., and Dilcher, D.L., 2003, Stratigraphy and megaflora of a K-T boundary section in the eastern Denver Basin, Colorado, *in* Johnson, K.R., Raynolds, R.G., and Reynolds, M.L., eds., Paleontology and stratigraphy of Laramide strata in the Denver Basin (Part II): Rocky Mountain Geology, v. 38, p. 45–71.

Benson, K.P., 1998, Floral diversity and paleoclimate of the latest Cretaceous and early Tertiary deposits, Denver Basin, Colorado, USA: Colorado Springs, Colo., Colorado College, Honors thesis, 178 p.

Benson, K.P., and Johnson, K. R., 1998, Fossil plants of the Late Cretaceous and early Tertiary, Denver Basin, CO, USA [abst.]: Geological Society of America, Abstracts with Programs, v. 30, no. 7, p A286.

Bryant, B., McGrew, L.W., and Wobus, R.A, 1981, Geologic map of the Denver 1° x 2° quadrangle, north-central Colorado: U.S. Geological Survey Miscellaneous Investigations Series I-1163, scale 1:250,000.

Carpenter, K., and Young, D.B., 2002, Late Cretaceous dinosaurs from the Denver Basin, Colorado, *in* Johnson, K.R., Raynolds, R.G., and Reynolds, M.L., eds., Paleontology and stratigraphy of Laramide strata in the Denver Basin (Part I): Rocky Mountain Geology, v. 37, p. 237–254.

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

Desbrough, G.A., Raymond. W.H., and Soule, C. 1970, Placer gold of unique fineness in Douglas and Elbert Counties, *in* Geological Survey Research 1970: U.S. Geological Survey Prof. Paper 700-D. p. D134–D139.

Eberle, J.J., 2003, Puercan mammalian systematics and biostratigraphy in the Denver Basin, Colorado, *in* Johnson, K.R., Raynolds, R.G., and Reynolds, M.L., eds., Paleontology and stratigraphy of Laramide strata in the Denver Basin (Part II): Rocky Mountain Geology, v. 38, 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.

Ellis, Beth, Johnson, K.R., and Dunn, R.E., 2003, Evidence for an in situ early Paleocene rainforest from Castle Rock, Colorado, *in* Johnson, K.R., Raynolds, R.G., and Reynolds, M.L., eds., Paleontology and stratigraphy of Laramide strata in the Denver Basin (Part II): Rocky Mountain Geology, v. 38, p. 73–100.

Epis, R.C., and Chapin, C.E., 1974, Stratigraphic nomenclature of the Thirtynine Mile volcanic field, central Colorado: U.S. Geological Survey Bulletin 1395-C, 23 p.

Farnham, T.M. and Kraus, M.J., 2002, The stratigraphic and climatic significance of Paleogene alluvial paleosols in synorogenic strata of the Denver Basin, Colorado, *in* Johnson, K.R., Raynolds, R.G., and Reynolds, M.L., eds., Paleontology and stratigraphy of Laramide strata in the Denver Basin (Part I): Rocky Mountain Geology, v. 37, p. 201 - 213.

Hicks, J.F., Johnson, K.R., Obradovich, J.D., Miggins, D.P., and Tauxe, L., 2003, Magnetostratigraphy of Upper Cretaceous (Maastrichtian) to lower Eocene strata of the Denver Basin, Colorado, *in* Johnson, K.R., Raynolds, R.G., and Reynolds, M.L., eds., Paleontology and stratigraphy of Laramide strata in the Denver Basin (Part II): Rocky Mountain Geology, v. 38, p. 1–27.

Izett, G.A., Scott, G.R., and Obradovich, J.D., 1969, Oligocene rhyolite in the Denver Basin, Colorado: U.S. Geological Survey Professional Paper 650-B, p. B12-B14.

Hilgard, E.W., 1892, A report on the relations of soil to climate: U.S. Department of Agriculture, Weather Bureau Bulletin 3, 59 p.

Hutchinson, J.H., and Holroyd, P.A., 2003, Late Cretaceous and early Paleocene turtles of the Denver Basin, Colorado, *in* Johnson, K.R., Raynolds, R.G., and Reynolds, M.L., eds., Paleontology and stratigraphy of Laramide strata in the Denver Basin (Part II): Rocky Mountain Geology, v. 38, p. 121–142.

Johnson, K. R., 2001, Fossil plants in the Denver Basin provide insight to climate, local habitat, extinction, and rainfall patterns related to uplift of the Front Range: Denver Basin Project Spring Science Meeting, Denver, May 18, 2001, unpublished conference abstract.

Johnson, K. R., and Raynolds, R.G., 1998, Field trip guide to the Upper Cretaceous and Lower Tertiary formations and fossil plants of the western Denver Basin: 15th Mid-continent Paleobotanical Colloquium, Denver, Colorado, May 10, 1998, unpublished conference field guide.

Johnson, K. R., and Raynolds, R.G., 2001, Research on paleontological and geological resources of the Denver Basin near Colorado Springs with emphasis on the Jimmy Camp Creek and Corral Bluffs area: 2000 Colorado Natural History Small Grants Program, Denver Museum of Nature and Science, Denver, Colorado, unpublished final report, 3 p.

Johnson, K. R., and Ellis, B., 2002, A tropical rainforest in Colorado 1.4 million years after the Cretaceous-Tertiary boundary; Science, v. 296, p. 2,379–2,383.

Johnson, K. R., Reynolds, M.L., Werth, K.W. and Thomasson, J.R., 2003, Overview of the late Cretaceous, early Paleocene, and early Eocene megafloras of the Denver Basin, Colorado, *in* Johnson, K.R., Raynolds, R.G., and Reynolds, M.L., eds., Paleontology and stratigraphy of Laramide strata in the Denver Basin (Part II): Rocky Mountain Geology, v. 38, p. 101–120.

Kelley, S.A., 2002, Unroofing of the southern Front Range, Colorado, a view from the Denver Basin, *in* Johnson, K.R., Raynolds, R.G., and Reynolds, M.L., eds., Paleontology and Stratigraphy of Laramide Strata in the Denver Basin (Part I): Rocky Mountain Geology, v. 37, p. 189–200.

Kelley, S.A., and Blackwell, D.D., 2002, Subsurface temperatures in the southern Denver Basin, Colorado, *in* Johnson, K.R., Raynolds, R.G., and Reynolds, M.L., eds., Paleontology and stratigraphy of Laramide strata in the Denver Basin (Part I): Rocky Mountain Geology, v. 37, p. 215–227.

Kluth, C.F., and Nelson, S.N., 1988, Age of the Dawson Arkose, southwestern Air Force Academy, Colorado, and implications for the uplift history of the Front Range: Mountain Geologist, v. 25, no. 1, p. 29–35.

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.

Madole, R.F., and Streufert, R.K., 2001, Geologic map of the Gibson Gulch quadrangle, Garfield County, Colorado: Colorado Geological Survey Open-File Report 01-2, 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,

Mcintosh, W.C., and Chapin, C.E., 1994, 40Ar/39Ar geochronology of ignimbrites in the Thirtynine Mile volcanic field, Colorado, *in* Evanoff, E., ed., Late Palogene geology and paleoenvironments of central Colorado: Geological Society of America Field Trip Guidebook, p. 23–26.

Mcintosh, W.C., Swisher, C.C., and Chapin, C.E., 1992, Single-crystal laser-fusion 40Ar/39Ar sanidine ages of ignimbrites in the Thirtynine Mile volcanic field, Colorado [abst.]: Eos, 1992 Spring Meeting Supplement, April 7, 1992.

Morgan, M.L., Temple, Jay, Grizzel, M.T., and Barkmann, P.E., 2004, Geologic map of the Dawson Butte quadrangle, Douglas County, Colorado: Colorado Geological Survey Open-File Report 04-0x, 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 Paleogeography Symposium 3: Society of Economic Paleontologists and Mineralogists, Rocky Mountain Section, Denver, Colo., p. 277–292.

Nichols, D.J., and Fleming, R.F., 2002, Palynology and palynostratigraphy of Maastrichtian, Paleocene, and Eocene strata in the Denver Basin, Colorado, *in* Johnson, K. R., Raynolds, R.G., and Reynolds, M.L., eds., Paleontology and stratigraphy of Laramide strata in the Denver Basin (Part I): Rocky Mountain Geology, v. 37, p. 135–163.

Obradovich, J.D., 2002, Geochronology of Laramided synorogenic strata in the Denver Basin, Colorado, *in* Johnson, K.R., Raynolds, R.G., and Reynolds, M.L., eds., Paleontology and Stratigraphy of Laramide Strata in the Denver Basin (Part I): Rocky Mountain Geology, v. 37, p. 165–171.

Parker, B.H., 1974, Gold Placers of Colorado, Book 1 of 2 books: Quarterly of the Colorado School of Mines, Golden, Colorado, v. 69, no. 3.

Raynolds, R.G., 2002, Upper Cretaceous and Tertiary stratigraphy of the Denver Basin, Colorado *in* Johnson, K.R., Raynolds, R.G., and Reynolds, M.L., eds., Paleontology and Stratigraphy of Laramide Strata in the Denver Basin (Part I): Rocky Mountain Geology, v. 37, p.111–134.

Raynolds, R.G., and Johnson, K.R., 2002, Drilling of the Kiowa core hole, *in* Johnson, K.R., Raynolds, R.G., and Reynolds, M.L., eds., Paleontology and Stratigraphy of Laramide Strata in the Denver Basin (Part I): Rocky Mountain Geology, v. 37, p. 105–109.

Raynolds, R.G., and Johnson, K.R., 2003, Synopsis of the stratigraphy and paleontology of the uppermost Cretaceous and lower Tertiary strata in the Denver Basin, Colorado *in* Johnson, K.R., Raynolds, R.G., and Reynolds, M.L., eds., Paleontology and Stratigraphy of Laramide Strata in the Denver Basin (Part II): Rocky Mountain Geology, v. 38, p. 171–181.

Raynolds, R.G., and Reynolds, M.L. editors, 2004, A special issue on bedrock aquifers of the Denver Basin: The Mountain Geologist, Rocky Mountain Association of Geologists, Denver, Colo., v. 41, no. 4, p. 145–217.

Remane, J., Faure-Muret, A. and Odin, G.S., 2002, International stratigraphiic chart: International Union of Geological Sciences and UNESCO Commission on the Geological Map of the World.

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

Robson, S.G., 1987, Bedrock aquifers in the Denver Basin, Colorado; A quantitative water-resources appraisal: U.S. Geological Survey Professional Paper 1257, 73 p., scale 1:500,000.

Robson, S.G., 1989, Alluvial and bedrock aquifers of the Denver basin; eastern Colorado's dual ground-water resource: U.S. Geological Survey Water-Supply Paper 2302, 40 p.

Rowley, P.D., Himmelreich, J.W., Jr., and Kupfer, D.H., 2002, Geological map of the Cheyenne Mountain quadrangle, El Paso County, Colorado: Colorado Geological Survey Open-file Report 02-05, scale 1:24,000,

Scott, G. R., 1962, Geology of the Littleton quadrangle, Jefferson, Douglas, and Arapahoe Counties, Colorado: U. S. Geological Survey Bulletin 1121-L, 53 p., map 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. 1–70.

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

Soister, P.E., and Tschudy, R.H., 1978, Eocene rocks in the Denver Basin, *in* Pruit, J.D., and Coffin, P.E., eds., Energy resources of the Denver Basin: Denver, Colo., Rocky Mountain Association of Geologists, 29th Annual Field Symposium Guidebook, p. 231–235.

Thorson, J.P., 2003a, Geologic map of the Black Forest quadrangle, El Paso County, Colorado: Colorado Geological Survey Open-File Report 03-6. scale 1:24,000.

Thorson, J.P., 2003b, 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., 2004a, Geologic map of the Castle Rock South quadrangle, Douglas County, Colorado: Colorado Geological Survey Open-File Report 04-5. 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 04-6. scale 1:24,000.

Thorson, J.P., 2005, Geologic map of the east half of the Larkspur quadrangle, Douglas and El Paso Counties, Colorado: Colorado Geological Survey Open-File Report 04-0x. scale 1:24,000, in preparation.

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.

Topper, R., Spray, K.L., Bellis, W.H., Hamilton, J.L., and Barkman, P.E., 2003, Groundwater atlas of Colorado: Colorado Geological Survey Special Publication 53, 210 p.

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.

Vanderwilt, J.W., 1947, Mineral Resources of Colorado: Colorado Mineral Resources Board, Denver, Colo.

Wheeler, E.A., and Michalski, T.C., 2003, Paleocene and Early Eocene woods of the Denver Basin, Colorado, *in* Johnson, K.R., Raynolds, R.G., and Reynolds, M.L., eds., Paleontology and stratigraphy of Laramide strata in the Denver Basin (Part II): Rocky Mountain Geology, v. 38, p. 29–43.

Wilson, M.D., 2002, Petrographic provenance analysis of Kiowa core sandstone samples, Denver Basin, Colorado, *in* Johnson, K.R., Raynolds, R.G., and Reynolds, M.L., eds., Paleontology and Stratigraphy of Laramide Strata in the Denver Basin (Part I): Rocky Mountain Geology, v. 37, p. 173–187.

Woodward, L.L., Sanford, W., and Raynolds, R.G., 2002, Stratigraphic variability of specific yield within bedrock aquifers of the Denver Basin, Colorado, *in* Johnson, K.R., Raynolds, R.G., and Reynolds, M.L., eds., Paleontology and stratigraphy of Laramide strata in the Denver Basin (Part I): Rocky Mountain Geology, v. 37, p. 229–236.