OPEN-FILE REPORT 05-6

Geologic Map of the Sedalia Quadrangle, Douglas County, Colorado

Bill Owens, Governor,
State of Colorado

COLORADO
DEPARTMENT OF
NATURAL
RESOURCES

Russell George, Executive Director,
Department of Natural Resources

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

by
Matthew L. Morgan, Jennifer L. McHarge, and Peter E. Barkmann

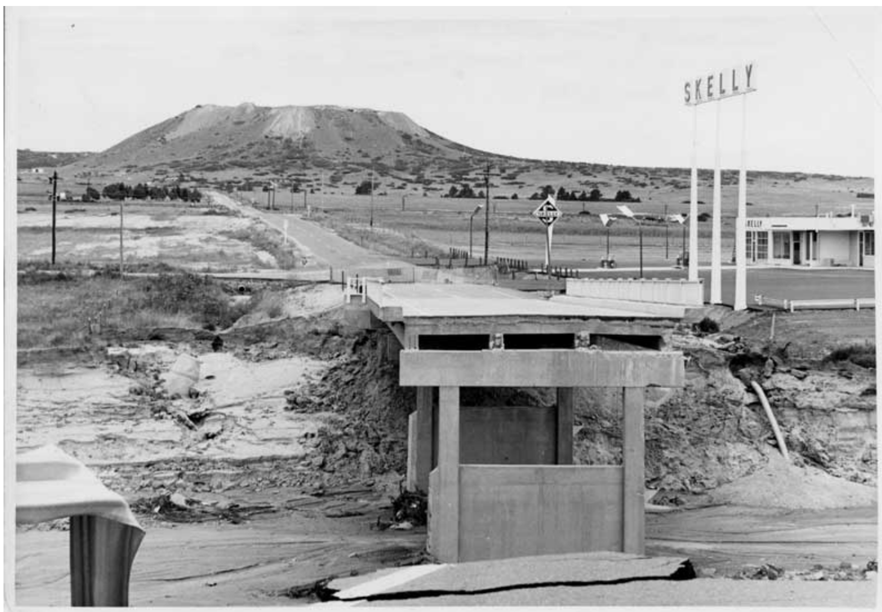
Colorado Geological Survey
Department of Natural Resources
Denver, Colorado
2005

OPEN-FILE REPORT 05-6

Geologic Map of the Sedalia Quadrangle, Douglas County, Colorado

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

by
Matthew L. Morgan, Jennifer L. McHarge, and Peter E. Barkmann
Colorado Geological Survey, Denver, CO



View of the Wolfensberger Road bridge, north of Castle Rock, looking west toward the Santa Fe Quarry (SW corner of the Sedalia quadrangle). The bridge is missing a large span across East Plum Creek and I-25. The damage occurred as the result of the June 1965 flood of East Plum Creek. Photo by Morris Flemming; image and caption courtesy of Douglas County Libraries.

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.

Bill Owens, Governor, State of Colorado
Russell George, Director, Department of Natural Resources
Vince Matthews, State Geologist and Division Director, Colorado Geological Survey
Denver, Colorado
2005

FOREWARD

The purpose of Colorado Geological Survey Open File Report 05-6, *Geologic Map of the Sedalia Quadrangle, Douglas County, Colorado* is to describe the geology, structural geology, mineral and water resources, and geologic hazards of this 7.5-minute quadrangle located northwest of the town of Castle Rock in central Colorado. Staff geologist Matthew L. Morgan and intern geologist Jennifer L. McHarge, completed the field work on this project during the summer of 2004. Staff hydrogeologist Peter E. Barkmann wrote the water resources section of this booklet.

This mapping project was funded jointly by the U.S. Geological Survey through the STATEMAP component of the National Cooperative Geologic Mapping Program which is authorized by the National Geologic Mapping Act of 1997, award number 04HQPA0003, and the Colorado Geological Survey using the Colorado Department of Natural Resources Severance Tax Operational Funds. The CGS matching funds come from the Severance Tax paid on the production of natural gas, oil, coal, and metals.

Vince Matthews
State Geologist and Division Director

TABLE OF CONTENTS

INTRODUCTION

The Sedalia 7.5-minute quadrangle is located in Douglas County, just east of the Colorado Front Range (figure 1). The town of Sedalia (2000 CENSUS population of 211) is located near the center of the quadrangle, along Highway 85. The town of Castle Rock (2000 CENSUS population of 20,224), located a few miles southeast of the quadrangle boundary, is the largest urban area nearby and serves as the seat of Douglas County. Plum Creek and West Plum Creek, the major drainages in the quadrangle, flow northward to meet the South Platte River near Denver. The highest point on the quadrangle is the rhyolite-capped butte in sec. 4 of T. 8 S., R. 67 W. (elevation 6,691 feet), and the lowest point (elevation 5,598 feet) is the Plum Creek valley bottom in the northwestern part of the quadrangle.

Geologic mapping of the Sedalia 7.5-minute quadrangle was undertaken by the Colorado Geological Survey (CGS) as part of the STATEMAP component of the National Cooperative Geologic Mapping Act, which is administered by the U.S. Geological Survey. Geologic maps produced by the CGS through the STATEMAP program are intended as multi-purpose maps useful for land-use planning, geotechnical engineering, geologic-hazards assessment, mineral-resource development, and ground-water exploration. Figure 2 shows the status of geologic maps of 7.5-minute quadrangles in the Castle Rock area. This is the eighth quadrangle in this area to be mapped by the CGS.

The geologic interpretations shown on the map were based on (1) field investigations in 2004; (2) prior published and unpublished geologic maps and reports; (3) study of black and white 1:20,000-scale Agricultural Stabilization Conservation Service (ASCS) aerial photography flown in 1965, a 10-meter digital elevation model (DEM), and a 1-meter resolution USGS digital orthophoto quadrangle (DOQ) derived from recent black and white photography. Bedrock geology and surficial deposits were mapped in the field on aerial photographs. The photos were scanned, georeferenced, and imported into ERDAS Imagine OrthoBase, where they were photogrammetrically corrected and rendered in 3D. Line work was traced directly from ERDAS Imagine Stereo Analyst and exported as ESRI shapefiles into ArcGIS 9.0.

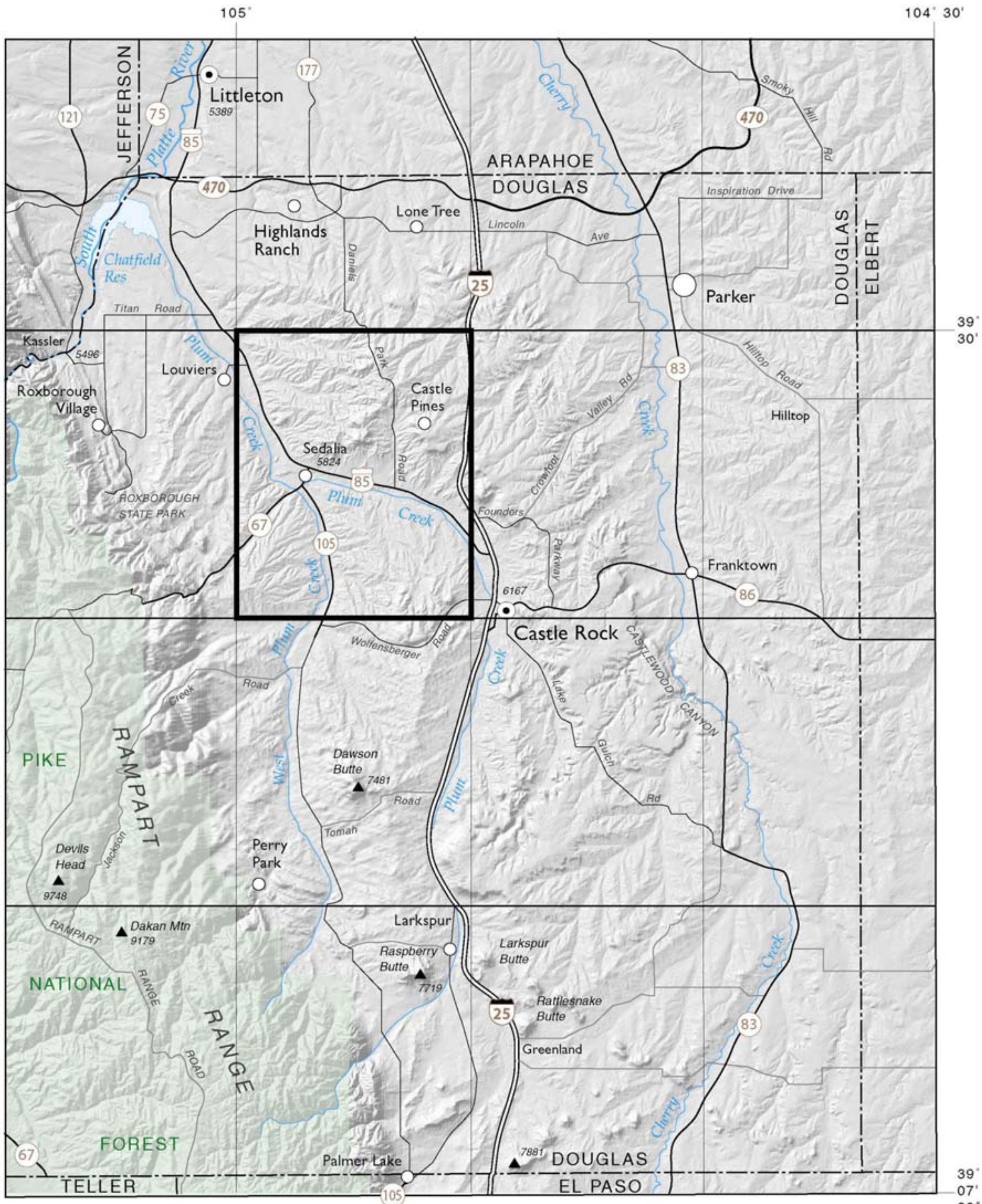


FIGURE 1. Location of the Sedalia quadrangle (**bold** black outline) in relation to major geographic features.

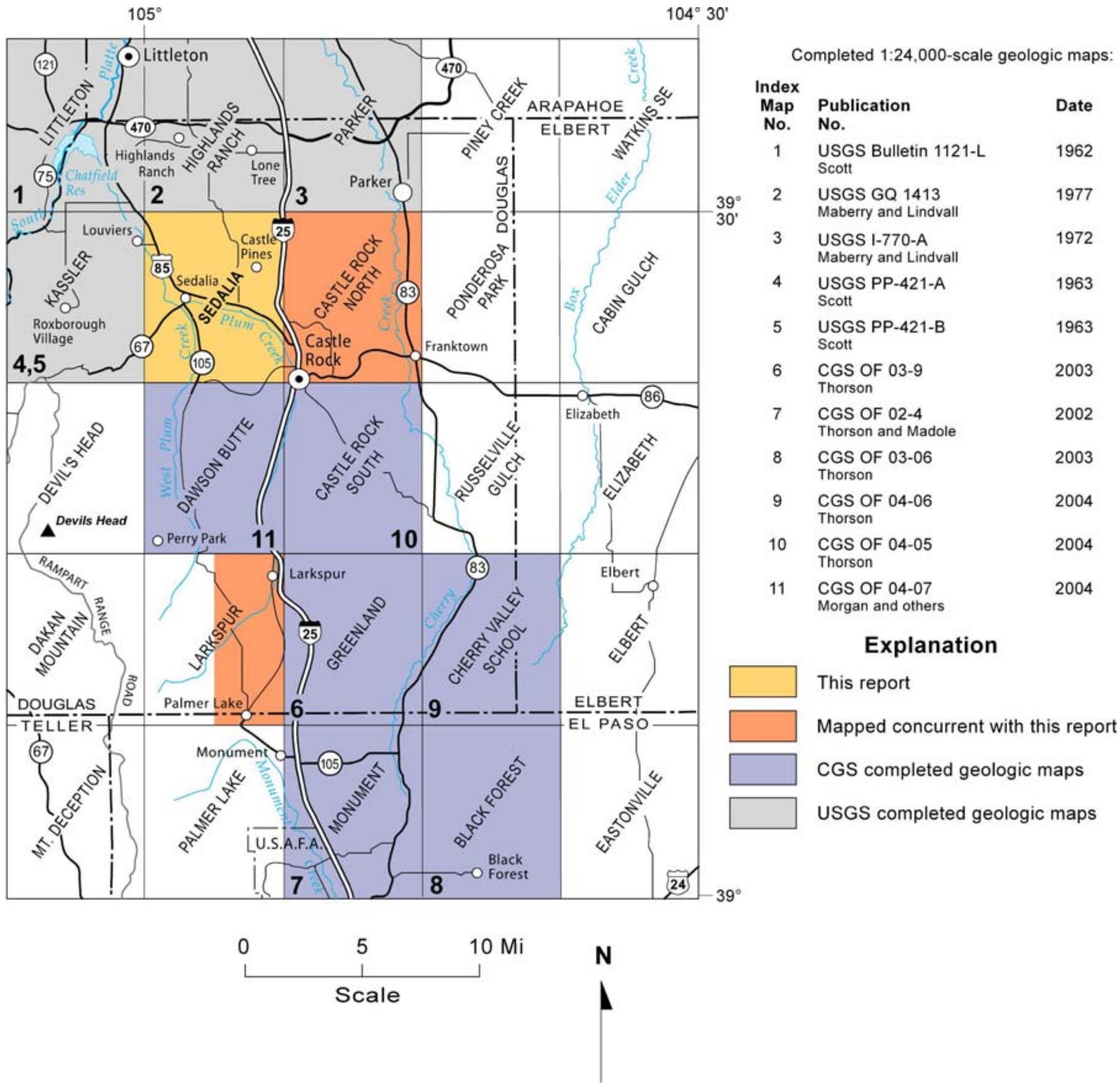


FIGURE 2. Index of published 1:24,000-scale geologic maps near Castle Rock and vicinity.

Geologic mapping of the Sedalia 7.5-minute quadrangle and surrounding area was done previously by Richardson (1916), Trimble and Machette (1979), and Bryant and others (1981). These small-scale maps were used as a guide to our mapping, especially in areas of intense urbanization. The Castle Rock North 7.5-minute quadrangle to the east was mapped by Thorson (2005a) concurrently with the Sedalia quadrangle. The Kassler and Littleton quadrangles, which lie to the west and northwest of the Sedalia quadrangle, were mapped by Scott (1962, 1963a, 1963b). The Highlands Ranch and Parker quadrangles, which lie to the northeast were mapped by Maberry and Lindvall (1972, 1977). The Dawson Butte quadrangle to the south and the Castle Rock South quadrangle to the southeast were mapped by and Morgan and others (2004) and Thorson (2004a), respectively.

ACKNOWLEDGMENTS

The Colorado Geological Survey and U.S. Geological Survey funded this mapping project jointly through the STATEMAP program of the National Cooperative Geologic Mapping Program under agreement no. 04HQPA0003. Partial funding for this project came from Colorado Severance taxes, which are derived from the production of oil, gas, coal, and minerals. Jon Thorson (consulting geologist), Bob Raynolds (Denver Museum of Nature & Science), Rich Madole (USGS emeritus geologist), and George VanSlyke (retired DWR hydrologist) provided valuable information on geologic interpretations and field observations. Karen Morgan (CGS) provided GIS and cartographic support and the cross-section profiles for the map plate. Larry Scott (CGS) provided assistance with figures for this book.

Access to private land was graciously provided by the following persons: Dave Curtis (Oaklands Ranch and Gravel), Al Koch and all the folks at the Cherokee Ranch, Lee Hall and family (Hall Ranch), Ed Ehmann (Castle Pines Metro District), and Sue Mantz (Castle Pines Metro District). Special thanks for road access goes to the following communities: Indian Creek Ranch, Monte Vista Estates, The Meadows, Town of Sedalia, Castle Pines, Castle Pines North, Charter Oaks, Beverly Hills, Oak Hills, Green Valley, Surrey Ridge, and Happy Canyon Ranch. We thank the Douglas County Assessor's Office for supplying land ownership information for many parts of the quadrangle. We thank Jan Ciener (technical editor), Bob Raynolds (Denver Museum of Nature & Science), Jon Thorson (consulting geologist), and Vince Matthews (CGS) for reviews of the map and manuscript. Paula Stokes (consultant) set the digital stereo models in ERDAS.

DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSITS

Surficial deposits shown on the map are generally more than 5 feet thick but may be thinner locally. Residuum, sheetwash, colluvium, and artificial fills of limited extent were not mapped. Contacts between surficial units may be gradational, and mapped units locally may include deposits of other types. Siderial age values given for the early, middle, and late Pleistocene Epoch are 1,806-778 ka (kilo-annum, 10^3 yr), 778-127 ka, and 127-11.7 ka, respectively (table 1). Age divisions for the Holocene used in the Sedalia quadrangle are arbitrary and informal. They are based chiefly on paleontological data compiled for the southwestern United States. Relative age assignments for surficial deposits are based primarily on the degree of erosional modification of original surface morphology, height above modern stream levels, degree of dissection and slope degradation, and soil development. Clast size is based on the modified Wentworth scale. The Front Range piedmont stratigraphic nomenclature of Quaternary alluvial deposits was established by Scott (1963b). Trimble and Machette (1979); Bryant and others (1981) applied this nomenclature to Quaternary deposits in the Sedalia quadrangle. To retain consistency with previous Colorado Geological Survey geologic maps in the Castle Rock-Colorado Springs area, the formal names for alluvial deposits were not used for the Sedalia quadrangle.

TABLE 1. Time divisions for the Quaternary from Madole and Thorson (2002).

Formal time divisions		Informal time divisions	**Age** (sidereal years)
Quaternary period	Holocene Epoch		~11,700
	Pleistocene Epoch	late Pleistocene	~127,000
		middle Pleistocene	~778,000
		early Pleistocene	~1,806,000
Neogene period (part)	Pliocene Epoch		

HUMAN-MADE DEPOSITS

af **Artificial fill (latest Holocene)** — Rip rap, engineered fill, and refuse placed during construction of roads, railroads, buildings, dams, and landfills. Generally consists of unsorted silt, sand, clay, and rock fragments. This unit may also include areas of construction and quarrying operations where original deposits have been removed, replaced, or reworked. The average thickness of the unit is less than 30 feet. Artificial fill may be subject to settlement and erosion if not adequately compacted.

ALLUVIAL DEPOSITS

Silt, sand, and gravel deposited in stream channels, on flood plains, on pediments, and as sheetwash along Plum and West Plum Creeks and associated tributary drainages. Terrace alluvium and related pediments along these mainstem creeks were deposited mostly during late-glacial and early-interglacial stages. The approximate terrace heights reported for each unit are the elevation differences measured between the creek bed and the top of the original or remnant alluvial surface near the creek edge of the terraces. Thickness is measured on the maximum exposed thickness of the unit.

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

Qa_1 Alluvium one (late Holocene) — Dark-yellow, brownish-gray to dark-brown, poorly to moderately sorted, poorly consolidated clay, silt, sand, gravel, and sparse boulders deposited as river terraces above the currently active flood plain or as non-terrace forming alluvium in valleys. The alluvium commonly forms steep-sided walls in arroyos. Clasts are subangular to well rounded and have varied lithology. Deposit commonly includes organic-rich layers interbedded with sand and gravel lenses. Terrace heights reach as much as 15 feet above current stream level. Maximum exposed thickness of unit locally exceeds 20 feet. The unit is generally correlative, by virtue of height and soil characteristics, with the Piney Creek Alluvium of the Denver area (Scott and Wobus, 1973) and Piney Creek and Post Piney Creek Alluviums of the adjacent Kassler quadrangle (Scott, 1963a). The unit is a potential source of commercial sand and gravel.

Qa_2 Alluvium two (early Holocene and late Pleistocene) — Dark-yellow to dark-brown, poorly to moderately sorted, poorly consolidated clay, silt, sand, gravel, and sparse boulders deposited as river terraces above the currently active flood plain or as non-terrace forming alluvium in valley headwaters. Clasts are subangular to well rounded and have varied lithology. Deposit commonly includes organic-rich layers interbedded with sand and gravel lenses. Terrace heights reach as much as 40 feet above current stream level. Maximum exposed thickness of unit locally exceeds 20 feet. The unit is correlative, by virtue of height and soil characteristics, with the Broadway Alluvium of the Denver area (Scott and Wobus, 1973) and adjacent Kassler quadrangle (Scott, 1963a). Holliday (1987) determined that deposition of the Broadway Alluvium ceased by 11 to 10 ka on the basis of geoarchaeological (Clovis people artifacts) evidence found in the alluvium in the Greeley area. Soil profile of the unit is characteristic of deposits associated with the Pinedale glaciation, which began approximately 30 ka and ended prior to 10 ka (Benedict, 1979;

Madole, 1986). The unit probably correlates with the latest stade of the Pinedale glaciation that began at about 15,000 B.P. and lasted until 10,000 B.P. (Benedict, 1979). The unit is a potential source of commercial sand and gravel.

Qa_3 Alluvium three (late middle Pleistocene) — Dark grayish-brown to yellow-reddish-brown, poorly to moderately sorted, moderately consolidated clay, silt, sand, gravel, and boulders deposited as river terraces above the currently active flood plain. Unit generally consists of a coarse-grained facies and a fine-grained facies; grain size is dependant upon stream discharge and basin size, with the coarser-grained sediments being restricted to larger streams. The upper 10 feet is typically wavy-bedded, fine-grained sand and clay; the lower part is cross-stratified sand and gravel. Soft sediment deformation features termed "flow rolls" by Pepper and others (1954, p. 88) are found locally at the contact between the upper and lower facies. These features are described by Scott (1963a). Graded bedding is common in both facies although it is more discontinuous in the coarse-grained facies. Clasts are subangular to well rounded and have varied lithology. Terrace heights reach as much as 60 feet above current stream level. Maximum exposed thickness of unit locally exceeds 80 feet. The unit is correlative, by virtue of height and soil characteristics, with the Louviers Alluvium of the Denver area (Scott and Wobus, 1973) and adjacent Kassler quadrangle (Scott, 1963a). The soil development on unit Qa_3 is greater than the soil developed on unit Qa_2, leading previous workers (Madole, 1969; Shroba, 1977; Madole and Shroba, 1979) to correlate the deposition of the Louviers Alluvium (Qa_3) with the Bull Lake glaciation. This correlation, however, is problematic since two uranium-series age dates of the Louviers Alluvium near Denver provided values of 129 $\pm$ 10 ka and 86 $\pm$ 6 ka (Szabo, 1980). The Bull Lake glaciation ended at approximately 130 ka and thus, only part of the Louviers Alluvium (Qa_3) may be correlative. Placer gold was recovered in minute quantities from Qa_3 deposits along West Plum Creek (Dave Curtis, personal commun., 2004) and was probably derived from the Castle Rock Conglomerate (J. Thorson, personal commun., 2005). The unit is a potential source of commercial sand and gravel.

Pediment gravels (Holocene to middle Pleistocene) — Partially dissected remnants of two levels of older gravel deposits are preserved along Plum and West Plum Creeks and at the base of butte escarpments on the piedmont. By definition, the deposits on this map with designation Qg meet the definition of "pediment" as supplied by the American Geological Institute's Glossary of Geology (Bates and Jackson, 1997):
"A broad gently sloping rock-floored erosion surface or plain of low relief, typically developed by subaerial agents (including running water) in an arid or semiarid region at the base of an

abrupt and receding mountain front or plateau escarpment, and underlain by bedrock (occasionally by older alluvial deposits) that may be bare but are more often partly mantled with a thin discontinuous veneer of alluvium derived from the upland masses and in transit across the surface."

Qg_1 Pediment gravel one (late-middle Pleistocene) — Light-red to brown, poorly sorted, moderately to poorly-stratified pebble, and cobble gravel derived from arkosic and granitic bedrock, as well as layers of clay, silt, sand and clay clasts derived from arkosic and shaly bedrock. Clasts are subrounded to rounded, moderately to highly weathered, and coated with a thin (less than 0.02-inch), discontinuous rind of calcium carbonate. Matrix typically consists of feldspar and quartz sand derived from weathered granite clasts and arkosic bedrock. Unit forms pediments and valley-fill terraces. Top of pediment gravel or terrace is 30 to 85 feet above adjacent modern streams. The unit locally exceeds 30 feet in thickness. Unit correlates with the Slocum Alluvium (Scott and Wobus, 1973) by virtue of height above stream level and degree of soil development. Pediment gravel one is considered to be middle Pleistocene in age on the basis of local stratigraphic and physiographic position and soil development. Scott and Lindavall (1970) collected a bison horn core from the lower part of the Slocum Alluvium near the Arkansas river that yielded calibrated uranium-series age of 190 ± 50 ka (Szabo, 1980). The deposit forms a stable building surface, but excavations may be prone to slumping. The unit is a source of sand and gravel.

Qg_2 Pediment gravel two (middle Pleistocene) — Medium-red to brown, poorly sorted, moderately to poorly stratified pebble, cobble, and boulder gravel derived from arkosic and granitic bedrock, as well as layers of clay, silt, sand and clay clasts derived from arkosic and shaly bedrock. Basal portion of unit contains layers of clay and silt interbedded with coarse-grained sand, cobble, and rare boulder gravels. Clasts are highly weathered and are coated with a thin (less than 0.05-inch), discontinuous rind of calcium carbonate. Matrix typically consists of feldspar and quartz sand derived from weathered granite clasts and arkosic bedrock. Becomes richer in boulders and less stratified toward mountain front or butte escarpment. Top of pediment gravel is 70 to 180 feet above adjacent modern streams. The unit locally exceeds 20 feet in thickness and in many places forms a thin, sometimes discontinuous, veneer over bedrock. Unit correlates with the Verdos Alluvium of the Denver area (Scott and Wobus, 1973) and adjacent Kassler quadrangle (Scott, 1963a). The unit is considered to be middle Pleistocene on the basis of local stratigraphic and physiographic position and soil development. In the adjacent Kassler quadrangle, the upper part of the

Verdos Alluvium contains Lava Creek B ash (Scott, 1963a), which was recently dated at 640,000 YBP (Lanphere and others, 2002). This unit forms a stable building surface; however, excavations may be prone to slumping. Unit is a source of sand and gravel.

Qgmv Gravel of Monte Vista (Holocene to middle Pleistocene) — Brownish-red to tan, poorly sorted, moderately to poorly stratified, pebble, cobble, and boulder gravel derived from erosion of the unnamed butte east of the Monte Vista Estates subdivision in the Dawson Butte quadrangle (Morgan and others, 2004). Found at southern edge of map area. Clasts are angular to subrounded and slightly weathered. Lithology consists of buff-colored Wall Mountain Tuff and white Dawson Formation. Matrix typically consists of quartz and feldspar sand from disaggregation of the Dawson Formation. Unit is thickest and coarsest near the butte escarpment and gradually thins and fines westward. Top of pediment gravel is 15 to 75 feet above modern streams but is variable when in close proximity to the butte. The unit locally exceeds 20 feet in thickness; however, in many places it forms a thin veneer over bedrock. The maximum age of the unit is considered to be middle Pleistocene on the basis of local stratigraphic position and soil development, which is similar to unit Qg_1 (middle Pleistocene). Some areas near the butte escarpment are actively accumulating sediment and may be prone to rockfall and flash flood events. Forms a stable building surface in areas of low grade. The unit is a source of sand and gravel.

Qg Pediment gravel, undivided (middle Pleistocene) — Red to light brown, poorly sorted, moderately to poorly stratified pebble and cobble gravel, derived from Dawson Formation and previously existing outcrops of Castle Rock Conglomerate. Clasts are subangular to rounded and moderately weathered. Lithology consists of buff-colored Wall Mountain Tuff, white Dawson Formation, and lesser amounts of milky quartzite, chert, and granite. Top of pediment gravel is 50 to 100 feet above modern streams. The unit locally exceeds 20 feet in thickness; however, in many places it forms a thin veneer over bedrock. The maximum age of the unit is considered to be late middle Pleistocene on the basis of local stratigraphic position and soil development, which is similar to unit Qg_1 (middle Pleistocene). Forms a stable building surface. The unit is a source of sand and gravel.

ALLUVIAL AND COLLUVIAL DEPOSITS — Gravel, sand, and silt in alluvial fans, stream channels, flood plains, tributary stream channels, and lower parts of hillslopes. Alluvial processes are predominant in stream channels and flood plains, whereas colluvial and sheetwash processes are predominant on alluvial fans and along the hillslope-valley floor boundary.

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

Qc_1 Colluvium deposit one (Holocene to middle Pleistocene) — Weathered bedrock fragments that consist of poorly sorted, clast-supported, pebble to boulder gravel in a sandy silt matrix. Unit contains angular to subangular clasts and is weakly stratified. Colluvial deposits derived from alluvial deposits contain rounded to subrounded clasts. Lithology is dependant on local bedrock sources. Significant deposits of colluvium deposit one occur on the slopes surrounding many of the buttes and mesas in the quadrangle. Freestanding colluvium-armored slopes are common throughout the mapped area and surrounding region. After a period of time (possibly hundreds to thousands of years), the butte slope that is actively collecting rock debris may recede and leave isolated colluvium-armored slopes (see Matthews and Morgan, 2004). The isolated slopes are often dissected by streams, which carry sediment outward where it is deposited as pediments or alluvial fans (see unit descriptions for more detail). The colluvium-armored slopes typically reach an angle of repose between 45 and 65 degrees. Commonly, the armored slopes form a series of nested flatirons in the shape of a ring surrounding a depression or small dome of weathered bedrock. The oldest slope is farthest from the center of the ring. Several colluvium rings are found south of the mapped area in the Dawson Butte and Greenland quadrangles. Colluvium of large cobble- and boulder-sized rock fragments may include rockfall debris. Deposits locally exceed 15 feet in thickness. Areas mapped as colluvium are susceptible to future rockfall events.

Qc_2 Colluvium deposit two (Holocene to middle Pleistocene) — Weathered bedrock fragments that consist of poorly sorted, clast-supported, pebble to boulder gravel in a sandy silt matrix. Unit contains angular to subangular clasts and is poorly stratified. Unit is differentiated from Qc_1 by preponderance of large blocks of Castle Rock Conglomerate.

Minor amounts of Dawson Formation constitute the supporting matrix. Some blocks of the Castle Rock Conglomerate reach 15 feet in their longest dimension. Significant deposits of colluvium deposit two occur on the slopes of hills in sec. 13, T. 7 S., R. 68 W. and sec. 10 and 11, T. 7 S., R. 68 W. These hills are the deflated remnants of buttes or mesas. The process of the deflation is as follows: (1) Jointing in the butte caprock (Castle Rock Conglomerate) widens, probably due to freeze/thaw wedging, (2) water from rain and/or snowmelt runoff seeps into the open joints and begins to erode the underlying, highly erosive Dawson Formation, (3) sediment derived from the Dawson Formation is transported away from the butte and is deposited as alluvial fans; this removal of material causes (4) downward displacement of the caprock from its original stratigraphic position forming colluvium-armored slopes. Compared to *in situ* outcrops of Castle Rock Conglomerate elsewhere in the quadrangle, the Castle Rock Conglomerate mantling these hills should be located at an elevation of 6500-6650 feet, approximately 230-380 feet above their current stratigraphic position. These colluvium covered deflated hills represent the earliest phases of colluvium ring development (see Qc_1 description above). Colluvium of large cobble- and boulder-sized rock fragments may include rockfall debris. Deposits locally exceed 15 feet in thickness. Areas mapped as colluvium are susceptible to future rockfall events.

Qf_1 Alluvial fan deposit one (late Holocene) — Dark-yellow to brownish-gray to dark-brown, poorly to moderately sorted, poorly consolidated clay, silt, sand, gravel, and boulders deposited as alluvial fans at the mouths of perennial streams. These deposits are similar to, and depositionally related to, unit Qa_1. They have a fan-like shape and consist of subangular to well-rounded clasts of varied lithology; however, sediment derived from the Dawson Formation is a major constituent. Sediments are deposited primarily by streams with significant input from sheetwash, debris flows, and hyperconcentrated flows. These fans host little vegetation and often divert the active stream channels into which they were deposited. Deposits locally exceed 10 feet in thickness. Areas mapped as alluvial fans are subject to future flash floods and debris flow events. Deposits may be prone to collapse, hydrocompaction, or slope failure when wetted or loaded. Deposit is a source of sand and gravel.

Qf_2 Alluvial fan deposit two (early Holocene to late-middle Pleistocene) — Dark-yellow-gray to dark-reddish-brown, poorly to moderately sorted, poorly consolidated clay, silt, sand, gravel, and boulders deposited as alluvial fans at the mouths of perennial streams. Clasts are subangular to well rounded and have varied lithology dependant upon source area. These deposits are similar to and depositionally related to units Qa_2 and Qa_3. They have a fan-like shape but are more dissected than younger Qf_1 deposits. Sediments are deposited primarily by streams with significant input from sheetwash, debris flows, and hyperconcentrated flows. The apex of the fan is as much as 50 feet above modern streams. Deposits locally exceed 20 feet in thickness. Areas mapped as alluvial fans are subject to future flash floods and debris flow events. Deposits may be prone to collapse, hydrocompaction, or slope failure when wetted or loaded. Deposit is a source of sand and gravel.

Qf Alluvial fan deposits, undivided (Holocene to middle Pleistocene) — Poorly sorted to moderately sorted, matrix-supported, gravelly, sandy silt to clast-supported, pebble and cobble gravel in a sandy silt or silty sand matrix. Clasts are mostly subangular to well rounded and typically composed of sediment derived from the Dawson Formation. Approximate age and relation to other alluvial units is unknown. Sediments are deposited primarily by streams with significant input from sheetwash, debris flows, and hyperconcentrated flows. Deposit locally is dissected and soil development is highly variable. The maximum estimated thickness locally exceeds 10 feet. Areas mapped as alluvial fans are subject to future flooding and debris flow events. Deposits may be prone to collapse, hydrocompaction, or slope failure when wetted or loaded. Deposit is a source of sand and gravel.

BEDROCK UNITS

Tcr Castle Rock Conglomerate (late Eocene) — The Castle Rock Conglomerate is an arkosic conglomerate composed of abundant pebbles, cobbles, and boulders in a quartz- and feldspar-rich matrix of subrounded to rounded, coarse to very coarse sand grains. It contains large pieces of chert and quartz up to 8 inches in size; however, the larger cobbles and boulders are composed primarily of maroon to lavender welded tuff eroded from deposits of the Wall Mountain tuff. The Castle Rock Conglomerate is younger than the Dawson Formation and the Wall Mountain tuff, which has been dated at 36.7 Ma (McIntosh and others, 1992; McIntosh and Chapin, 1994). On the basis of fossilized bones of *titanotheres* (late Eocene) the unit must be older than the end of the Eocene (Thorson 2003a). A thin, less than 5-foot-thick, paleosol is locally present beneath the Castle Rock Conglomerate in the adjacent Dawson Butte and Castle Rock North quadrangles. It consists of a mottled red and white clay-rich zone with root and plant casts, lying at an elevation of 6580 feet in the Dawson Butte quadrangle and at 6500 feet at Castle Rock Butte (Castle

Rock North quadrangle), where part of it is cut out by an ancestral Castle Rock Conglomerate channel. Unit reaches a maximum thickness of 80 feet.

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, 1975). The unit is exposed on Raccoon Knob and two other areas in sec. 7 of T. 7 S., R. 67 W., and a butte in sec. 4 of T. 8 S., R. 67 W., where it has been mined as road base and landscape and dimension stone. The mine is known as the Santa Fe Quarry and operated in the late 1800s (see the Mineral Resources section). At these locations it is light to medium brown to pink in fresh samples and reddish brown to maroon where weathered. The fine-grained felsic groundmass contains small phenocrysts of quartz, sanidine, and biotite. The Wall Mountain Tuff is interpreted to be an ash flow that was sufficiently hot at the time of its emplacement to become compacted, welded, and exhibit flow banding before solidifying. The age of the Wall Mountain Tuff is 36.7 Ma (McIntosh and others, 1992; McIntosh and Chapin, 1994). Definitive Source(s) for the Wall Mountain Tuff are still unknown. Epis and Chapin (1974) suggested that the Mount Aetna cauldron was the possible source for the Wall Mountain Tuff. Chapin and Lowell (1979) placed the caldera source of the Wall Mountain Tuff in the southern part of the Sawatch Range, northwest of Salida. Flow distribution measurements by McIntosh and Chapin (2004), suggest it was erupted from calderas in the Sawatch Range, including part of the Thirtynine Mile Volcanic field. The thickest exposure of the Wall Mountain Tuff in the Sedalia quadrangle is at the Santa Fe Quarry, where the formation measures about 50 feet. The Wall Mountain Tuff displays localized columnar jointing on the faces of this butte. It is difficult to determine if the Wall Mountain Tuff in NE¼ SW¼ and SE ¼ NW ¼, sec. 7 of T. 7 S., R. 67 W. is in place. The outcrops are highly fractured and relationships to the Castle Rock Conglomerate are puzzling, as the Wall Mountain Tuff appears to be sitting above it; although erosion has destroyed much of the Castle Rock Conglomerate in this area. Furthermore, the outcrops may have been used as quarries for the construction of local buildings in sec. 7 of T. 7 S., R. 67 W.

Tlc Conglomerate of Larkspur Butte (late? Eocene) — The conglomerate of Larkspur Butte is described by Thorson (2003b) as a pink to pinkish-brown arkosic conglomerate. Rounded to subrounded clasts of white to gray quartz and pink granite are common. The conglomerate has large clasts of eroded Dawson Formation near the base of the unit and large sets of cross beds are suggestive of a channel-type deposit. The conglomerate of Larkspur Butte is exposed in the Castle Pines subdivision in secs. 9 and 16, T. 7 S., R. 67

W. Thorson (2003b) reports that the unit has a thickness of up to 120 feet on Best Butte in the Greenland quadrangle. At the Castle Pines location, the unit reaches a thickness of just over 60 feet. The conglomerate is similar in appearance to the Castle Rock Conglomerate but does not contain the characteristic fragments of the Wall Mountain Tuff. The unit can be distinguished from the underlying Dawson Formation by the larger clasts, predominance of pink granite, and lack of clay in the matrix material.

Dawson Formation (Upper Cretaceous to Eocene) — Previous studies within the Denver Basin have investigated the genesis of the Dawson Formation. There is consensus that the sedimentary rocks of the Dawson Formation are the erosional debris deposited by braided streams flowing from the uplifting of crystalline rock of the Front Range during the Laramide orogeny (Tweto, 1975; Epis and others, 1980; Raynolds, 1997, 2002; Thorson and others, 2001). However, characterizations of the lateral and vertical changes in stratigraphy vary considerably. Raynolds (1997, 2002), Thorson and others (2001), and Thorson and Madole (2002) provide a synopsis of the earlier work on the Dawson Formation stratigraphy that is beyond the scope of this discussion. Further information on the depositional setting and age control for this unit (Figure 3) comes from the Denver Basin project of the Denver Museum of Nature & Science (Raynolds and Johnson, 2003).

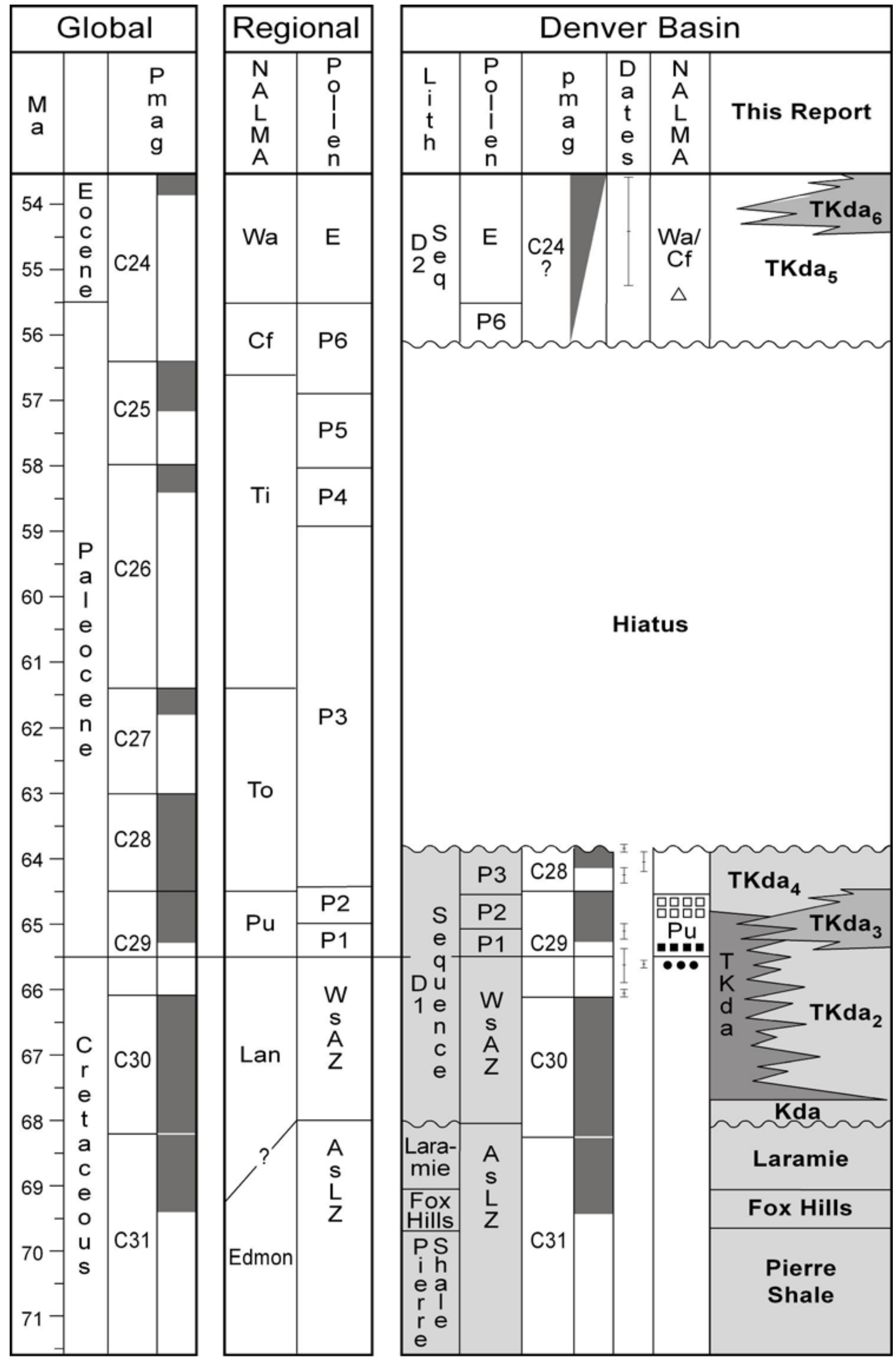


FIGURE 3. Relationships between Denver Basin stratigraphy and age dates and global and regional age dates (modified from Raynolds and Johnson, 2003) and the stratigraphic framework of Thorson and others (2001) and Thorson and Madole (2002). Left column is the global geomagnetic timescale (modified from Cande and Kent, 1995). Center column is regional mammalian biostratigraphy (modified from Woodburne and Swisher, 1995 and Gingerich, 2001) and palynostratigraphy (modified from Nichols, 1994; Nichols and Ott, 1978). Right column is Denver Basin lithostratigraphy of Raynolds (2002), palynostratigraphy, magnetostratigraphy,

radiometric dates and error bars (Soister and Tschudy, 1978; Obradovich, 2002; Hicks and others, 2002) mammalian biostratigraphy, and lithostratigraphy of Thorson and others (2001) and Thorson and Madole (2002) used in this report. Abbreviations for playnostratigraphy: WsAZ = *Wodehouseia spinata* Assembalge Zone; AsIZ = *Aquilapollenites striatus* Interval Zone. Abbreviations for North American Land Mammal Ages (NALMAs): Edmon = Edmontonian; Lan = Lancian; Pu = Puercan; To = Torrejonian; Ti = Tiffanian; Cf = Clarkforkian; Wa = Wasatchian. Triangle is Coryphodon tooth; open squares are Pu2/3 mammal sites; closed squares are Pu1 mammal sites; closed circles are dinosaur sites.

Several authors divided the Dawson Formation into upper and lower parts in the area east of the Front Range from Colorado Springs to Denver (Dane and Pierce (1936), Soister and Tschudy (1978), Raynolds (1997, 2002); Thorson and others (2001)). Dane and Pierce (1936) mapped the geology of the southeastern part of the Denver Basin and divided the Dawson Formation into a coarse upper member and a heterolithic lower member (Raynolds, 2002). Soister and Tschudy (1978) combined geologic mapping, stratigraphy, and palynology to place the Paleocene-Eocene boundary within the Dawson Formation beneath a basin-wide paleosol. This paleosol approximates the boundary between the upper and lower members of the Dawson Formation.

Raynolds (1997) related the deposition of the Arapahoe conglomerate, Denver Formation, and the Dawson Formation to the uplift of the central Front Range during Laramide time. He grouped these synorogenic strata into two regionally correlative, unconformity-bound sequences, termed D1 and D2. Both the D1 and D2 sequences are fluvial in origin. Both units are arkosic sandstones; however, locally the D1 sequence contains volcanic rock fragments (Raynolds, 2002). The base of the D1 sequence is at the unconformity between the fine-grained strata of the underlying Laramie Formation and the coarse, fluvial deposits of the overlying Arapahoe conglomerate (Raynolds, 2002). The paleosol series described by Soister and Tschudy (1978) and reexamined by Farnham and Kraus (2002) lies above the D1 sequence and its base serves as the D1/D2 boundary. Approximately eight million years of time is missing at this unconformity (Raynolds, 2002).

Overlying the mudstones at the top of the D1 sequence and the paleosol series are the arkosic channel deposits and overbank mudstones of the D2 sequence (Raynolds, 2002). The arkose was derived from the grusifcation and redistribution of Pikes Peak Granite and also contains very rare amazonite pebbles, presumably from Crystal Peak to the west of the mapped area (Raynolds, 2002). Raynolds (2002) suggests the D2 sequence is derived from grus shed from the Pikes Peak region. The widespread Rocky Mountain erosion surface (Scott and Taylor, 1986) forms the upper boundary of the D2 sequence. This surface could be early Tertiary (Epis and others, 1980) or, possibly, late Tertiary (Steven and others, 1997).

Thorson (2003a,b) and Thorson and Madole (2002) have differentiated the upper part of the Dawson Formation into six facies units on the basis of differences in composition of andesitic and arkosic materials, thicknesses and styles of coarse-grained bedding, proportions of claystones and siltstones relative to sandstone, and locations of paleosol zones indicating periods of erosion and soil formation. The six units are: facies unit one ($TKda_1$), facies unit two ($TKda_2$), facies unit three ($TKda_3$), facies unit four ($TKda_4$), facies unit five ($TKda_5$), and facies unit six ($Tkda_6$). The lower part of the Dawson Formation, which is Upper Cretaceous in age, and facies units two and three are either not present or not exposed in the Sedalia quadrangle.

The authors here must qualify that facies unit one ($TKda_1$) may crop out in the Sedalia quadrangle but because facies units four ($Tkda_4$) and one ($TKda_1$) are so similar in composition and texture, they are indistinguishable without the presence of either facies unit two or facies unit three. Therefore, the $TKda_1$ does not appear as a mapped unit on the Sedalia quadrangle map.

The total thickness of facies $TKda_4$ and $Tkda_1$ and the lower part of the Dawson Formation (labeled "Kda" on figure 4) is at least 1,920 feet on the basis of logs from an abandoned petroleum exploration well that was drilled in 1953 in sec. 16, T. 8 S., R. 67 W. in the adjacent Dawson Butte quadrangle. The well, State Lease #1 operated by J.S. Abercrombie Mineral Exploration, began drilling in facies unit four ($Tkda_4$) and encountered the top of the Laramie at 1,920 feet below the surface. No petroleum wells were drilled in the Sedalia quadrangle.

The stratigraphic relationships of these units are represented in figure 4, which is a slight modification from Thorson and Madole (2002). Facies $Tkda_4$ through $Tkda_1$ and the lower part of the Dawson Formation correlate with the D1 sequence of Raynolds (1997, 2002) (figure 3). Facies $Tkda_5$ and $Tkda_6$ correlate with Raynolds' (1997, 2002) D2 sequence.

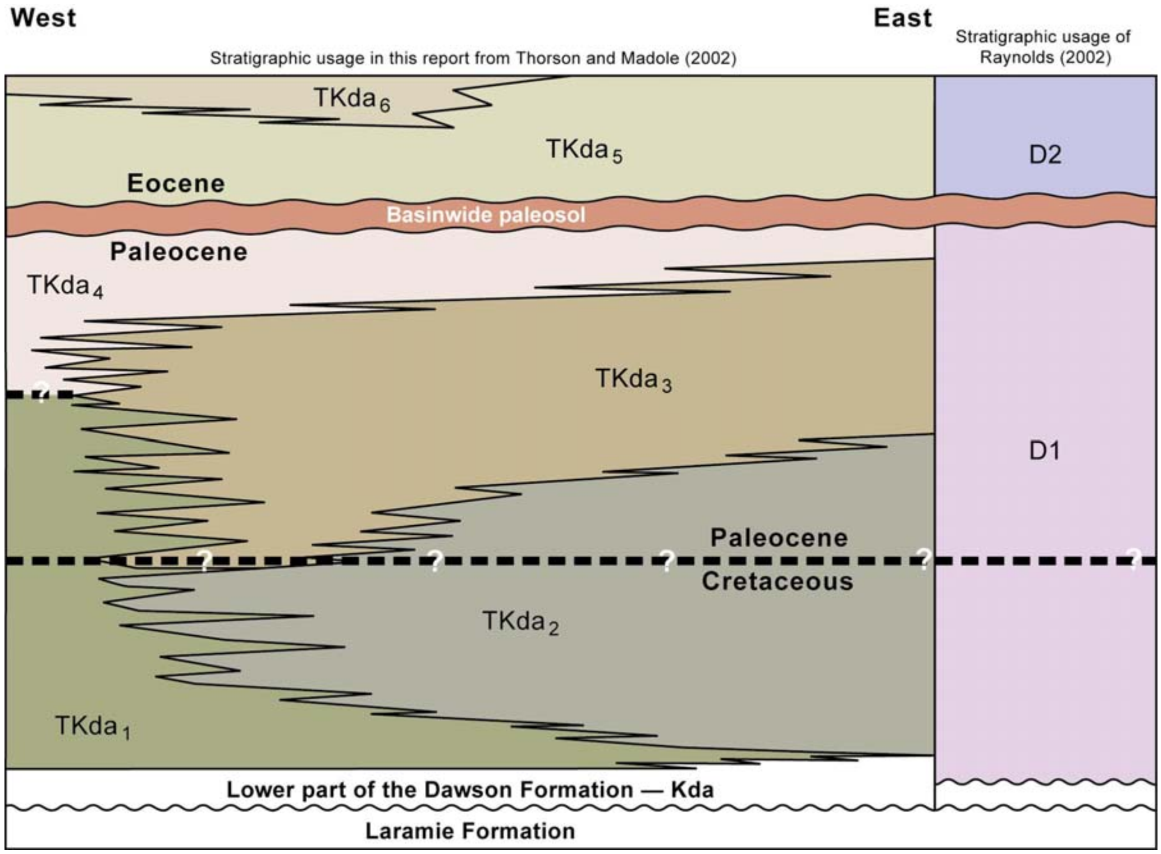


FIGURE 4. Diagrammatic sketch showing the regional relationships between the facies units of the Dawson Formation in the Sedalia area. The Sedalia quadrangle is roughly represented by the center of the diagram. The local facies units of Thorson and Madole (2002) are shown in relation to the basinwide sequences of Raynolds (2002). Heavy dashed lines indicate the approximate stratigraphic location of geologic time lines. Wavy lines are unconformities; the basinwide paleosol separates $TKda_4$ and $TKda_5$ as well as the D1 and D2 sequences of Raynolds (2002). This sketch was modified from Thorson and Madole (2002) by adding the stratigraphic usage of Raynolds (2002) and the newly recognized unit $Tkda_6$.

TKda$_5$ Facies unit five (latest Paleocene to middle? Eocene) — The TKda$_5$ unit is an arkosic conglomerate consisting of subangular to well-rounded clasts of quartz and feldspar up to several inches in size. The unit is white to light-gray to tan, friable to well cemented, and weathers to a darker tan to light brown with notable iron staining. Outcrops are thick bedded to massive and often contain spectacular cross beds indicative of channel deposition. Fresh exposures of these arkosic sands are white to cream colored as a result of bleaching of the feldspars during diagenetic alteration. Significant lenses of fine clays up to several feet in thickness are suggestive of channel overbank deposits. These clay zones are also white to cream to light gray in color. Fragments of amazonite crystals were found at several locations, some measuring 2 inches in longest dimension. Thickness of facies unit five is estimated to be about 500 feet on the basis of cross section A - A'.

The Tkda$_5$ unit is separated from the underlying Tkda$_4$ by a distinct zone of gray to pink to dark red clays up to 40 feet thick interpreted to represent a paleosurface of soil formation which also approximates the Paleocene — Eocene boundary (Raynolds, 2002; Thorson and Madole, 2002; Thorson, 2003a,b). The distinctly different weathered colors and clay-rich content between the coarser grained TKda$_5$ and TKda$_4$ facies units make this zone recognizable. This zone also contains abundant root casts and a distinct mottled character. It is mapped as the paleosol in sec. 33, T. 7 S., R. 67 W., in the Sedalia quadrangle.

TKda$_4$ Facies unit four (early Paleocene) — The TKda$_4$ unit is a tan, brown, or light orange to orange arkosic conglomerate containing subangular to subrounded cobbles of quartz, feldspar, and occasional granite up to 8 inches in size. Thick-bedded to massive zones are up to 40 feet in thickness and frequently contain large sets of cross beds, some with field relations suggesting stream flow from northwest to southeast. Above and below the massive zones are occasional 8 to 10 foot thick lenses of thinly bedded white to cream, fine-grained, rounded to well rounded arkosic sands that weather to a tan to light-brown color. Very fine-grained sands and lenses of clays up to 3 feet thick are interpreted to be channel overbank deposits similar to those described in facies unit five. Soft-sediment deformation was also observed in many of these clay lenses. Dark-red to maroon, iron-rich zones form bedding-like planes that most probably represent paleowater tables and not true attitudes (Thorson, 2003, oral communication). In the adjacent Dawson Butte quadrangle, this unit forms discontinuous hogback ridges along the eastern side of Highway 105. Due to faulting to the west and south of the Sedalia quadrangle, these outcrops have been uplifted and tilted eastward. They are characterized by quartz- and feldspar-rich, medium- to coarse-grained fluvial channels interbedded with debris flow deposits and may represent the remnants of distributary alluvial fans. Local paleosols are found associated with these outcrops and are probably well-drained portions of the fans. Furthermore, like the Wildcat Mountain distributary fan in the adjacent Kassler quadrangle (Raynolds and Johnson, 2003), the outcrops have a fan-shaped surface morphology; the deposits are thicker on the apex and become thinner a few hundred feet laterally from the apex. Thickness of facies unit four is estimated to be about 1,250 feet on the basis of cross section A - A'.

STRUCTURAL GEOLOGY

Between 40 and 80 Ma, the Laramide Orogeny resulted in the formation of basement-cored uplifts throughout Colorado and adjacent states, including the Front Range of central Colorado. As the basement was exposed in fault-bounded, upthrown blocks, synorogenic arkosic sediments of the Arapahoe Conglomerate and Dawson Formation were rapidly deposited from alluvial fans and braided streams along the eastern mountain front. The subsiding Denver Basin to the east of the uplifted range front acted as a trap for this debris. Portions of these formations became important aquifers in the Denver Basin.

Robson and others (1998) mapped a normal fault trending approximately N40E along Jarre Creek and ending near the town of Sedalia. Evidence for this fault as cited by G. Van Slyke (personal communication, 1/26/2005) includes: (1) Denver Formation on the northern, upthrown side; this was based on geophysical logs of water wells in the area where thin-bedded sands and lignite beds were assigned to the Denver Formation, and (2) changes in surficial soils across the fault as mapped on the Douglas County Soil Survey (Larsen, 1974), (3) the relatively linear alignment of Jarre Creek, and (4) proximity and similar trend to a fault mapped cutting Precambrian rocks by Böos and Böos (1957) in the adjacent Kassler quadrangle. Van Slyke (personal communication, 1/26/2005) suggested there may be as much as 100 feet of vertical displacement on the fault on the basis of geophysical log correlations. This cannot be confirmed in the field.

We cite additional evidence for the existence of this fault as: (1) preponderance of paleosols on the northern, upthrown side and apparent lack of these paleosols on the southern, downthrown side. Formation of soil horizons requires the landscape to be well drained and exposed to weathering processes. The northern, upthrown block of this fault provided such an environment. (2) Thicker deposits of alluvial gravels on the downthrown fault block. These alluvial gravels were deposited on pediment surfaces that were cut across bedrock. On the downthrown block, the thickness of the gravel deposit may reach 10 feet. However, on the upthrown block, the gravel deposits range in thickness from 0 to 3 feet. The downthrown block may have acted as a sedimentary basin and collected greater amounts of alluvium than the higher, upthrown block. We chose to extend the fault farther northeast into sec. 7, T. & S., R 67 W., where it forms the northern boundary of the last outcrops of Castle Rock Conglomerate (Tcr) and Wall Mountain Tuff (Twm) in the quadrangle. Beyond this point, the fault cannot be extended with confidence.

Away from the mountain front, the structural geology of the Sedalia quadrangle largely consists of gentle regional dips, primarily within the Dawson Formation, of less than ten degrees to the east-northeast. Strike and dip symbols are not abundant on the western half of the map because of poor outcrop exposures in the map area. Many bedding surfaces, such as cross-beds or channel scour surfaces, were inclined at the time of deposition and are unlikely to be representative of true structural attitudes (Thorson, 2003a,b). The structure of the younger bedrock deposits is similarly gentle; the Wall Mountain Tuff was deposited on a surface that sloped to the NE at about 100 feet per mile (Thorson, 2004a,b).

GEOLOGIC HAZARDS

The geology and geomorphology in the Sedalia quadrangle makes many areas susceptible to a wide variety of geologic hazards such as debris flows, rockfall, and swelling soils. For example, in 1965 many drainages and low-lying areas were devastated by major debris flows caused by flooding. Over two-dozen people perished in the 1965 flood, which caused over $540 million in damage (City of Littleton Homepage, http://www.littletongov.org/history/othertopics/flood.asp). Although less damaging than the 1965 event, eight other flood events occurred from 1864 to 1983.

Heaving and erosive bedrock and soils are a prevalent hazard to homeowners in the area, accounting for tens of millions of dollars in damage over the last decade (K. Berry, Colorado Geological Survey, personal communication; Noe and others, 1997; Noe, 1997). Other significant and potentially damaging hazards in the mapped area include earthquakes, rockfall, and hydrocompactive soils.

Debris Flows (Mudslides)

Debris flows are heterogeneous mixtures of mud, rock fragments, and plant materials that commonly form in the lower parts of tributary streams as they enter a large valley (Rogers and others, 1974). As the debris flow moves down its valley, unconsolidated surficial material is incorporated into the flow until the suspended sediment is no longer confined and is released as a fan-shaped deposit at the mouth of the tributary stream.

Debris flows are the result of torrential rainfall or very rapid snowmelt runoff, where sediment supply is abundant and easily mobilized (Selby, 1993). Hazard analysis should take into account denuded forest conditions, such as after a wildfire. Such conditions may exist in areas mapped as alluvial fans (Qf), colluvium (Qc), and sheetwash (Qsw).

Major debris flows and floods associated with large precipitation events have affected many parts of the Sedalia quadrangle. Some of the flooding events were very serious, resulting in loss of human life, livestock, and property. According to regional and local newspaper articles, large historic floods in Douglas County occurred in the years 1864, 1885, 1912, 1921, 1933, 1935, 1965, 1973, and 1983. The June 16-17, 1965 event killed 28 people, demolished State Highway 85 (now I-25), washed out fourteen bridges between Castle Rock and Denver and laid waste to numerous homes and businesses (figures 5 and 6). President Lyndon Johnson declared the affected region a federal disaster area. Evidence of the 1965 flood still exists in the mapped area; fragments of concrete, rebar, roof shingles, and other debris are found stranded several feet above the current flood plain and tributary streams of Plum and West Plum Creeks. The deposits are commonly composed of sand and gravel derived from the Dawson Arkose along with cobble- and boulder-sized fragments of Castle Rock Conglomerate and Wall Mountain Tuff. Summaries of the other flood events can be found on-line at http://history.dpld.org/floods/.

A wildfire, caused by a downed power line, swept through the Daniels Park and Cherokee Ranch areas on October 29, 2003. The fire burned over 1200 acres of grassland and forest and destroyed three structures. Due to the lack of vegetation and bare soil, the burned area is highly susceptible to debris flows and erosive soils, especially during high precipitation events.

A

B

FIGURE 5. Two photographs taken during the flood of 1965 showing destruction of a church. A) The Presbyterian Church south of Sedalia being inundated by the rising waters of Plum Creek and B) the church is destroyed. Photos by Bobbie Elder; image courtesy of Douglas County Libraries.

FIGURE 6. A bridge on Highway 67 south of Sedalia is washed out during the flood of 1965. Fragments of concrete, rebar, and other construction materials are still found in the alluvial deposits of Plum and West Plum Creeks. Cherokee Mountain is visible in the background. Photo by Charles Love; image courtesy of Douglas County Libraries.

Rockfall

Rockfall deposits are included in the colluvium unit (Qc) in the Sedalia quadrangle. Of particular concern are the extensive colluvium deposits covering the steep slopes surrounding Cherokee Mountain, the butte in sec. 7 T. 7 S., R. 67 W., and the mesa in secs. 9 and 16 of T. 7 S., R. 67 W. in the Castle Pines subdivision. Blocks of Dawson Arkose, Castle Rock Conglomerate, and Conglomerate of Larkspur Butte may reach tens of feet in exposed diameter. Large precipitation events and freeze-thaw processes may trigger rockfall or rock avalanches. The area is extremely susceptible to future rockfall events; developers and homeowners should be extremely cautious when building in proximity to these unstable cliffs.

Angular blocks of Wall Mountain Tuff form colluvium deposits along the flanks of the butte in secs. 3 and 4, T. 8 S., R 67 W. Some of the blocks may reach 3 feet in exposed diameter. The upper 2 to 4 feet of the deposits are unstable due to lack of matrix material and sparse vegetation. Most of the blocks are waste rock from quarrying operations.

Earthquakes

On November 14, 1965, a magnitude 4.8 earthquake was recorded by the USGS National Earthquake Information Center (NEIC) (Kirkham and others, 2004). The epicenter of the event is located in the middle of sec. 29, T. 6 S., R. 67 W.; however, this event is poorly located. No additional details are given for this event.

On December 25, 1994, a magnitude 4.0 earthquake was recorded by the USGS NEIC, about 5.6 miles southeast of Castle Rock. The epicenter was relocated by MicroGeophysics Corporation (1995) to approximately 2.5 miles north of Perry Park, probably along the Rampart Range-Jarre Canyon fault zone (Morgan and others, 2004), at a depth of 14.6 miles. The earthquake was felt at intensity V at Palmer Lake and Larkspur (Kirkham and others, 2004). Additional information on faulting and earthquakes in this area can be found in the CGS' Colorado Earthquake Map Server (Kirkham and others, 2004) or the Colorado Late Cenozoic Fault and Fold Database and Internet Map Server (Widmann and others, 2002). Both are available for no charge on-line at *http://geosurvey.state.co.us.*

Swelling soils and heaving bedrock

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

Past studies along the Front Range Urban Corridor of potentially swelling soils (Hart, 1974) and heaving bedrock (Noe and Dodson, 1999) place a low to moderate probability for expansive clays in the Sedalia quadrangle. Areas particularly susceptible are west of West Plum Creek. Some of the soils in this area are derived from the Pierre shale and other claystone formations located farther west. Clay layers within the Dawson Formation also have the potential for swelling. Proper investigation and engineering practices, with a focus on expansive clays and heaving bedrock, should be applied during construction in these areas.

Hydrocompactive soils

Soils that are susceptible to hydrocompaction (settlement or collapse due to the addition of water) may exist in areas mapped as alluvial fans (Qf), colluvium (Qc) and sheetwash (Qsw). However, no cases of damage from hydrocompaction have been reported in the mapped area.

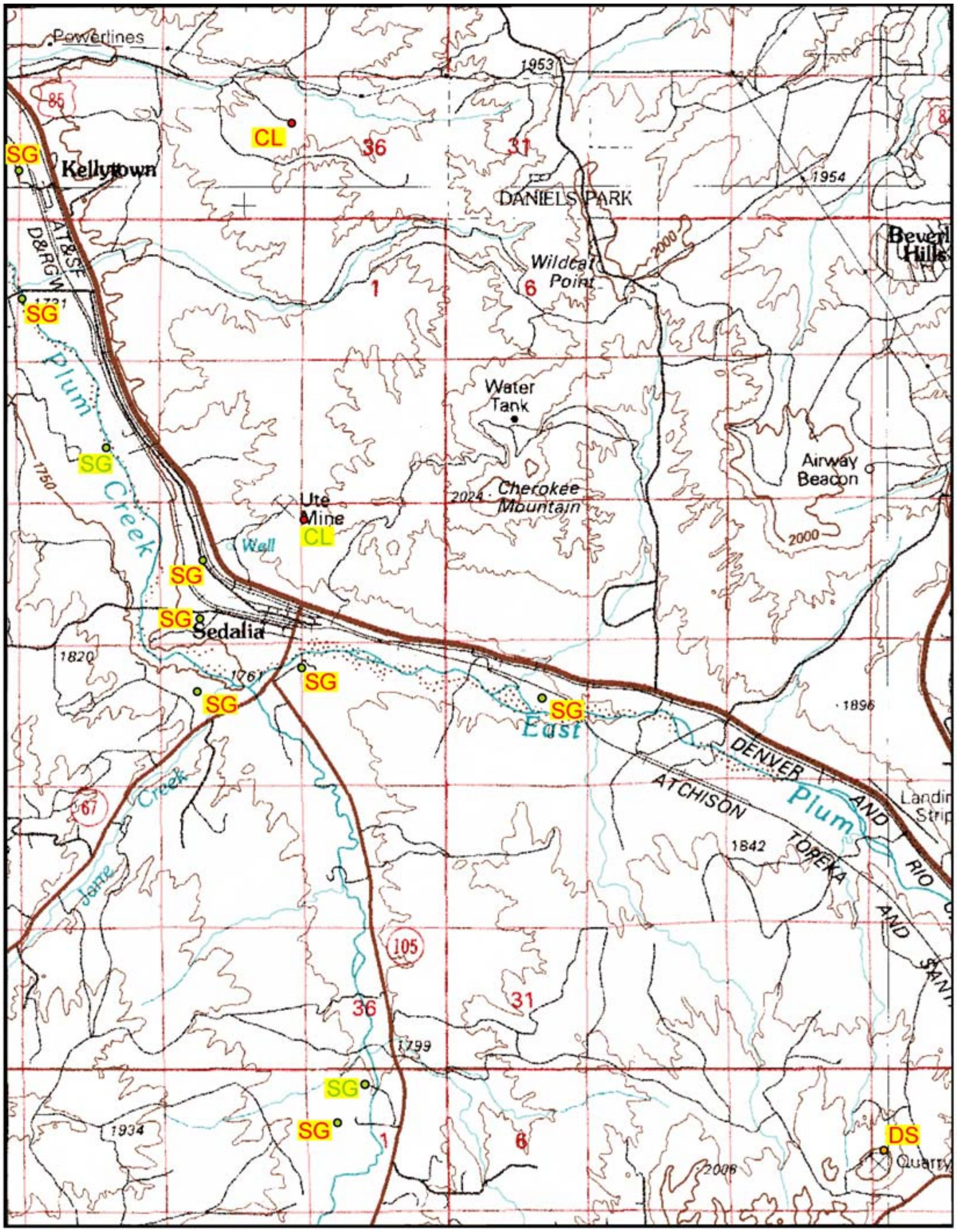
Erosive soils

Soil erosion is one of the most visible geologic hazards in the mapped area. Wind and water runoff are the biggest causes of erosion, however these are amplified by development and grazing of vegetated lands where the soil is exposed and easily eroded. Upland areas and terraces in the mapped area are susceptible to moderate to severe soil erosion, especially where vegetation has been removed (Larsen, 1974). The Meadows subdivision is particularly susceptible to soil erosion due to the modification of the original drainage ways. While mapping in August of 2004, the author witnessed severe runoff after a moderately heavy rainstorm. Because the original drainage pathways were diverted or blocked, water could not escape and flooding occurred. Small debris fans of Dawson-derived sediment were deposited in the roadways.

Erosion may adversely affect the respiratory functions of humans and livestock by reducing air quality from airborne dust. Furthermore, there is an increased risk of pollution to surface and ground waters due to use of nutrients and pesticides from agricultural and residential treatment of vegetation.

MINERAL RESOURCES

Sand and gravel are presently the most economically significant mineral resources on the Sedalia quadrangle. Two active aggregate mines are located in the mapped area. Rhyolite from the Wall Mountain Tuff was used for building stone during the late-1800s and early-1900s, but demand for the stone dwindled and production ceased soon after. Clay from the Dawson Formation is currently used to manufacture brick and was mined in the past in the quadrangle. Potential exists for the development of additional sand and gravel operations in the significant alluvial deposits in the mapped area and thick paleosols may provide quality clay for brick. Figure 7 shows the locations of the currently active and inactive mines within the quadrangle.



Explanation

Commodity

SG	sand and gravel (active)	CL	clay, claystone, shale (active)	DS	rhyolite dimension stone
SG	sand and gravel	CL	clay, claystone, shale		

FIGURE 7. Location of mineral resource areas in the Sedalia quadrangle, Douglas County, Colorado.

Construction aggregates (crushed rock and sand and gravel)

Two sand and gravel operations are currently active in the quadrangle. Eight other sand and gravel pits were once active, however, these have ceased operation and are in various stages of reclamation (Keller and others, 2002). In addition to sand and gravel, crushed stone may also be produced from these operations.

The Plum Creek Pit located in sec. 10, T. 7 S., R. 67 W. is producing from Quaternary alluvial gravel units Qa_2 and Qa_3. It is owned by Lafarge of Denver and operated by Mobile Premix Concrete, Inc. No production information is given.

The Oaklands Ranch Pit in sec. 1 of T. 8 S., R. 67 W. is producing from Quaternary alluvial gravel unit Qa_3. The owner and operator is Oaklands Ranch Gravel of Sedalia. It produced over 28,000 tons of sand and gravel in 2002 (Guilinger and Keller, 2004).

Gravel has been mined in the past from Quaternary alluvium along Plum and West Plum Creeks. Production values for these operations are not reported. Stream alluvium (Qa) and alluvial fan deposits (Qf) were the most common sources of aggregate from these areas.

Clay

Clay from the Dawson Formation is currently being mined in the quadrangle to produce brick for building stone. Robinson Brick Company is mining brick clay from the Ute Mine located in sec. 13, T. 7 S., R. 68 W. According to the mine site chief, the clay is buff to red in color, is interbedded with sandy lenses, and varies in thickness from 0 to 50 feet. The clay is most likely not the basin-wide paleosol, but is reworked clay and sand from the Laramie Formation. The paleosols in the mapped area are potential targets for future clay mining operations.

Dimension Stone

In the early 1870s, Colorado's first large-production dimension stone was fashioned from the Wall Mountain Tuff (Twm) (Schwochow, 1981). This light pink, maroon, and gray rhyolite was erupted from ancient volcanoes in south and central Colorado during late Eocene time and now caps many buttes in the Castle Rock area. The inactive Santa Fe Quarry (figure 7) in sec. 3, T. 8 S., R. 67 W. produced building stone from the Wall Mountain Tuff during the late 1800s when several rhyolite quarries operated on buttes in the area. Rhyolite was a boon for the economy of Castle Rock, so much that the Santa Fe Railroad put a one-mile spur to a quarry west of town. In 1900, over 1800 train cars with a value of

$10 per car, were filled with Wall Mountain Tuff and shipped around the country to be used as architectural stone (Marr, 1983).

FIGURE 7. Miners pose in the Santa Fe Quarry west of Castle Rock. Blocks of Wall Mountain Tuff were mined here for dimension stone beginning in 1889. Image courtesy of Douglas County Libraries

Coal

The Sedalia quadrangle is within the Denver coal region and is only a few miles east of the formerly productive Foothills coal field (Carroll and Bauer, 2002). Although there were never any coal mines in the Sedalia quadrangle, several historic underground mines once operated within 2 miles of the eastern quadrangle boundary in the adjacent Kassler quadrangle. Two historic mines, Cannon and White Ash, produced 21,050 tons of coal between 1884 and 1886 (Carroll and Bauer, 2002).

In the adjacent Kassler quadrangle, coal was mined from three seams within the lower part of the Cretaceous Laramie Formation. The mined seams range in thickness from 5 to 9.5 feet and are generally lenticular. Coal quality data were not reported, however, they are listed as subbituminous in Carroll and Bauer (2002).

Oil and Gas

Much of the Sedalia quadrangle lies along the western edge of the Denver Basin, a major oil and gas producing area in the Rocky Mountain region. However, no wells were ever drilled in the mapped area. The potential for future oil and gas production in the quadrangle is unknown, but probably unrealistic due to the housing development in the area and shallow depth of possible producing horizons. Oil and gas is generally produced from the center of the Denver Basin where greater depths and pressures favor the generation of fossil fuels. The nearest producing oil and gas fields are located 20 miles to the northeast of the quadrangle. These fields generally produce from the "J" and "D" sands of the Dakota Sandstone (Wray and others, 2002).

GROUND-WATER RESOURCES

Ground water provides the primary water source for agricultural and domestic purposes throughout the Sedalia quadrangle. Depending on location, ground water can be found in one or two hydrogeologic units: (1) Quaternary alluvial aquifers along the streams that run through the quadrangle, or (2) consolidated bedrock aquifers found in the late Cretaceous and Paleogene fluvial deposits of the Denver Basin. The following sections describe each of these hydrogeologic units and provide general hydrogeologic characteristics gathered from available literature. The scope of this discussion is limited to providing a general description of the ground-water resources that might be available within the quadrangle, further details, such as specifics about water quality conditions and current water level data can be obtained from cited literature.

Quaternary Alluvium

Quaternary alluvial deposits associated with Plum Creek and its major tributary, West Plum Creek, along with several lesser tributaries form a major aquifer system in the Sedalia quadrangle. The major streams follow well-defined valleys underlain with alluvial sand and gravel derived from the foothills of the Rocky Mountains as well as the locally exposed sedimentary rocks. The aerial extent of the alluvium is limited to relatively narrow bands along each creek, depicted on the geologic map as Qa, Qa_1, Qa_2, and $Qa_{3.}$ These generally increase in width downstream to the north. South, and upstream, of the confluence of West

Plum Creek with Plum Creek, the width of the alluvium is slightly over ½ mile, while north, and downstream of the confluence, the width of the alluvium approaches one mile.

Well permit files maintained by the State of Colorado Division of Water Resources (DWR) provide limited thickness data for the alluvium. Accurate geologic logs for wells in the alluvium are rare; however, reported well depths might provide an estimation of depth. Caution should be exercised using reported well depths since it is never clear where drilling was terminated relative to the basal contact. It can only be assumed that the wells were installed to take advantage of the most favorable geologic materials for water production, which we infer to be the entire saturated alluvial sequence. On the basis of well records and topographic expression of the alluvial valleys, the thickness of the alluvium approaches 125 feet beneath terraces near the center of the Plum Creek valley at the downstream (northern) end.

The alluvium is in direct hydraulic connection with the streams and forms an unconfined aquifer where saturated with ground water. The aerial extent of the alluvial aquifer roughly coincides with the aerial extent of the alluvium, however, the alluvium is not always saturated with ground water and the presence of alluvium at the surface does not imply the presence of an aquifer at depth. On the basis of records obtained from the DWR, water levels in wells completed in the alluvial aquifer generally lie between the surface and approximately 60 feet below the surface. The aerial extent of the alluvial aquifer, therefore, would be expected to be somewhat smaller than that of the alluvium.

When provided in the permit files, the alluvium has simply been described as sand and gravel with “rocks.” In the adjacent Kassler quadrangle, Scott (1963a,b) suggested the alluvial fill beneath the current stream channels was comprised of a thin mantle of Post-Piney Creek Alluvium (Qa_1, this map) above Pre-Wisconsin Slocum Alluvium (mapped at the surface on this map as Qg1).

The coarse-grained nature of the unconsolidated alluvium allows very high well yields, with rates over 1,500 gallons per minute (gpm) possible, particularly near the confluence of West Plum Creek with Plum Creek (Hillier and others, 1983). The highest reported yield in the DWR records is 1,800 gpm from a trench (Permit No. 5894-F) in sec. 23, T. 7 S., R. 68 W.

In general, the water quality in the alluvial aquifer is suitable for domestic use. Locally, the water contains concentrations of fluoride, iron, manganese, and nitrate that exceed applicable drinking water standards (Hillier and others, 1983).

The Denver Basin Bedrock Aquifer System

The Denver Basin bedrock aquifer system underlies much of the Denver/Colorado Springs metropolitan area and supplies ground water to domestic, commercial, municipal, and agricultural users throughout the region. Held within the Denver structural basin, this important aquifer system is comprised of Eocene through Upper Cretaceous water-bearing sands and conglomerates in the Dawson Formation through the Fox Hills Sandstone sedimentary sequence. The hydrogeologic conditions of the Denver Basin bedrock aquifers are summarized in the Ground-Water Atlas of Colorado (Topper and others, 2003). The Denver Basin bedrock aquifers underlie the entire Sedalia quadrangle and form the primary water supply where the Quaternary alluvial aquifers are not resent.

Detailed descriptions of the sedimentary rocks comprising the Denver Basin bedrock aquifers are presented in the literature (Raynolds, 2004; Robson, 1983; Topper and others, 2003) as well as elsewhere in this report; however, in short, the sedimentary sequence consists of interbedded sandstone, conglomerate, siltstone, and shale with local coal. Ground water is produced from the more porous and permeable sandstone layers of the sequence. By statute, for the purposes of managing water use, the Denver Basin bedrock aquifer system has been subdivided into the Dawson, Denver, Arapahoe, and Laramie-Fox Hills aquifers (Graham and VanSlyke, 2004). In this area, the Dawson aquifer is further subdivided into the Upper and Lower Dawson aquifers. Water rights allocations and well permits are granted based on these designations.

Separation of the Denver Basin bedrock aquifers is based on correlation of laterally extensive, shale-dominant, confining layers identified on borehole geophysical logs (primarily gamma-ray and resistivity logs) by the USGS and the DWR. The DWR has prepared a series of structural contour maps showing the elevation of the top and base of each of the Denver Basin aquifers based on the correlations of the confining layers separating the aquifers. These maps are part of the Denver Basin rules (Colorado DWR, 1986) and are used for determining well depths based on location.

The depths to the Denver Basin bedrock aquifers are a function of topographic relief and the regional dip of the Denver Basin to the east beneath the Sedalia quadrangle. Nearest to the surface is the Upper Dawson aquifer, which is only found beneath topographically elevated areas; elsewhere, the Upper Dawson aquifer has been incised by the modern stream drainages. As the result of elevated topography and regional dip, the base of the Upper Dawson aquifer can be as deep as 700 feet below the surface in the southeast corner of the quadrangle. The main stem of Plum Creek has also incised through the Lower Dawson aquifer in the northwestern corner of the quadrangle where the aquifer is not present. However, the Lower Dawson can be found beneath topographically elevated areas on the east side of the quadrangle where the depth to the base can reach approximately 1,050 feet. The other Denver Basin bedrock aquifers are present beneath the entire quadrangle with the greatest depths found on the east side beneath topographically elevated areas. For the Denver aquifer, the depth to the base ranges between approximately 300 feet beneath the northwest corner of the quadrangle to 1,900 feet along the eastern edge. Similarly the depth to the base of the Arapahoe aquifer ranges from approximately 800 to 2,500 feet and the Laramie Fox Hills aquifer from approximately 1,500 to 3,100 feet.

Water level data for the Denver Basin aquifers can be obtained from the DWR well permit files. Well completion reports and pump installation reports for wells that are required to be submitted often have listed water levels recorded when the wells were completed. However, water level information does not necessarily represent static conditions in the well and the data are one-time measurements. Water levels in the Denver Basin bedrock aquifers can be expected to vary considerably depending on location and elevation; values listed in the DWR permit base range between 22 and 1,680 feet below the surface.

Reported water level measurements in the Denver Basin bedrock aquifers are also time dependant. The DWR measures water levels in a number of select wells throughout the Denver Basin on an annual basis in order to track regional water level changes (Colorado DWR, 2004). On a regional basis, water levels in the Denver, Arapahoe, and Laramie-Fox Hills aquifers are declining rapidly in response to exploitation of ground water at rates that exceed natural recharge (Moore and others, 2004). This rapid water level decline is particularly evident at wells completed in the Arapahoe aquifer throughout the west-central portion of the Denver Basin (Raynolds, 2004) where the Sedalia quadrangle is located. Data from wells in the Castle Pines area, in the northeastern corner of the quadrangle, indicate water level declines of approximately 15 feet per year for the Denver aquifer (Permit 16393-F) and up to 42 feet per year for the Arapahoe aquifer (Permit 27993-F). Water levels at the IREA Laramie-Fox Hills aquifer well near Sedalia (Permit 23968-F) have been declining at a rate of approximately 20 feet per year. These declines reflect heavy reliance on the Denver Basin aquifer system to meet increasing water demands. Water levels in the lower Dawson aquifer, on the other hand, appear to be more stable based on the data published by the DWR. Those data show water levels rising approximately 2 feet per year at a Castle Pines lower Dawson well (Permit 38404-F) and declining approximately 3 feet per year in a nearby well located just east of the Sedalia quadrangle in section 27, T.7S., R.67W. (Permit 8891-RF).

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

Water quality data for the Denver Basin bedrock aquifers has been summarized in a set of maps published by the USGS (Robson and Romero, 1981a,b; Robson and others, 1981a,b). Hillier and others (1983) also presented limited data on near surface water quality of the Dawson aquifer. Otherwise, there is little published water quality data from locations within the Sedalia quadrangle. In general, the water quality of the Denver Basin aquifers is adequate for domestic uses. However, there can be concerns with elevated total dissolved solids and sulfate in the Denver and Laramie-Fox Hills aquifers elsewhere in the Denver Basin. Elevated concentrations of dissolved iron have also been reported in water from each of the aquifers.

REFERENCES CITED

Bates, R.L., and Jackson, J.A., eds.,1997, Glossary of geology, 3rd: Alexandria, Va., American Geological Institute, CD-Rom.

Benedict, J. B., 1979, Fossil ice-wedge polygons in the Colorado Front Range — Origin and significance: Geological Society of America Bulletin v. 90, no. 2, p. 173-180.

Böos, C.M., and Böos, M.F., 1957, Tectonics of eastern flank and foothills of Front Range, Colorado: American Association of Petroleum Geologists Bulletin, v. 41, no. 12.

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 1:250000.

Cande, S.C., and Kent, D.V., 1995, Revised calibration of the geomagnetic polarity timescale for the Late Cretaceous and Cenozoic: Journal of Geophysical Research, v. 100, p. 6093-6095.

Carroll, C.J., and Bauer, M.A., 2002, Historic coal mines of Colorado: Colorado Geological Survey Information Series 64, CD-Rom.

Chapin, C.E., and Lowell, G.R., 1979, Primary and secondary flowstructures in ashflow tuffs of the Gribbles Run paleovalley, central Colorado *in* Chapin, C.E., and Elston, W.E. (eds.), Ashflow tuffs — Geological Society of America, Special Paper 180, p. 136-153.

Colorado Division of Water Resources (DWR), 1986, Denver Basin Rules: 2 Colorado Code of Regulations 402-6, effective January 30, 1987.

Dane, C.H., and Pierce, W.G., 1936, Dawson and Laramie formations in southeastern part of Denver Basin, Colorado: Bulletin of the American Association of Petroleum Geologists, no. 20, v. 10, p. 1308-1328.

Epis, R., and Chapin, C., 1975, Geomorphic and tectonic implications of the post-Laramide, late Eocene erosion surface in the Southern Rocky Mountains, *in* Curtis, B.F., ed., Cenozoic history of the Southern Rocky Mountains: Geological Society of America Memoir 144, p. 45-74.

Epis, R.C., Scott, G.R., Taylor, R.B., and Chapin, C.E., 1980, Summary of Cenozoic geomorphic, volcanic and tectonic features of central Colorado and adjoining areas, *in* Kent, H.C., and Porter, K.W., eds., Colorado geology: Rocky Mountain Association of Geologists, 1980 symposium, p. 135-156.

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: Rocky Mountain Geology, v. 37, p. 201-213.

Gingerich, P.D., 2001, Biostratigraphy of the continental Paleocene-Eocene boundary interval on Polecat Bench in the northern Bighorn Basin, *in* Gingerich, P.D., ed., Paleocene-Eocene stratigraphy and biotic change in the Bighorn and Clark's Fork Basins, Wyoming: University of Michigan Papers in Paleontology 33, p. 33-71.

Graham, G., and VanSlyke, G., 2004, Development of the regulatory framework for the Denver Basin aquifers: The Mountain Geologist, v. 41, n. 4, p. 153-160.

Guilinger, J.R., and Keller, J.W., 2004, Directory of active and permitted mines in Colorado – 2002: Colorado Geological Survey Information Series 68.

Hart, S.S., 1974, Potentially swelling soil and rock in the Front Range Urban Corridor, Colorado: Colorado Geological Survey, Environmental Geology 7, 23 p.

Hicks, J.F., Johnson, K.R., Obradovich, J.D., Tauxe, L., and Clark, D., 2002, Magnetostratigraphy and geochronology of the Hell Creek and basal Fort Union Formations of southwestern North Dakota and a recalibration of the age of the Cretaceous-Tertiary boundary, *in* Hartman, J.H., Johnson, K.R., and Nichols, D.J., eds., The Hell Creek Formation and the Cretaceous-Tertiary boundary in the Northern Great Plains — an integrated continental record of the end of the Cretaceous: Geological Society of America Special Paper 361, p. 35-36.

Hillier, D.E., Schneider, P.A., and Hutchinson, E. C., 1983, Well yields and chemical quality of water from water-table aquifers in the greater Denver area, Front Range Urban Corridor, Colorado: U.S. Geological Survey Miscellaneous Investigations Series I-856-J, 2 sheets, scale 1:100,000.

Holliday, V.T., 1987, Geoarchaeology and late Quaternary geomorphology of the middle South Platte River, northeastern Colorado: Geoarchaeology, v. 2, p. 317-329.

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.

Keller, J.W., Phillips, R.C., Morgan, K., 2002, Digital inventory of industrial mineral mines and mine permit locations in Colorado: Colorado Geological Survey Information Series 62, CD-Rom.

Kirkham, R. M., Rogers, W. P., Powell, L., Morgan, M. L., Matthews, V., and Pattyn, G. R., 2004, Colorado Earthquake Map Server: Colorado Geological Survey Bulletin 52b, http://geosurvey.state.co.us/pubs/eq/.

Lanphere, M.A., Champion, D.E., Christiansen, R.L., Izett, G.A., and Obradovich, J.D., 2002, Revised ages for tuffs of the Yellowstone Plateau volcanic field – Assignment of the Huckleberry Ridge Tuff to a new geomagnetic polarity event: Geological Society of America Bulletin, v. 114, no. 5, p. 559-568.

Larsen, L.S., 1974, Soil survey of Castle Rock area, Colorado: U.S. Department of Agriculture, Soil Conservation Service, 124 p. and plates

Maberry, J.O. and Lindvall, R.M., 1972, Geologic map of the Parker quadrangle, Arapahoe and Douglas Counties, Colorado: U.S. Geological Survey, Miscellaneous Geologic Investigations I-770-A, scale 1:24000.

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 GQ-1413, scale 1:24000.

Madole, R.F., 1969, Pinedale and Bull Lake glaciation in upper St. Vrain drainage basin: Arctic and Alpine Research, v. 1, p. 279-287.

Madole, R.F., 1986, Lake Devlin and Pinedale glacial history, Front Range, Colorado: Quaternary Research, v. 25, p. 43-54.

Madole, R.F., and Shroba, R.R., 1979, Till sequence and soil development in the North Str. Vrain drainage basin, east slope, Front Range, Colorado, *in* Ethridge, F.G., ed., Field guide, northern Front Range and northwest Denver Basin, Colorado: Fort Collins, Colorado State University Department of Earth Resources, p. 123-178.

Madole, R.F., and Thorson, J.P., Geologic map of the Elsmere quadrangle, El Paso County, Colorado: Colorado Geological Survey Open-File Report 02-2, scale 1:24000.

Marr, J.L., 1983, Douglas County – A historical journey:, Gunnison, Colo., B & B Printers, 276 p.

Matthews III, V., and Morgan, M. L., 2004, From buttes to bowls — Repeated inversions in the landscape of the Colorado Piedmont: Geological Society of America Annual Meeting Abstracts with Programs, v. 36, no. 5, p. 411.

McIntosh, W.C., and Chapin, C.E., 2004, Geochronology of the central Colorado volcanic field: New Mexico Bureau of Geology and Mineral Resources Bulletin 160, p. 205-237.

McIntosh, W.C., and Chapin, C.E., 1994, $^{40}Ar/^{39}Ar$ 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 $^{40}Ar/^{39}Ar$ sanidine ages of ignimbrites inn the Thirtynine Mile volcanic field, Colorado: [abst]: Eos, 1992 Spring Meeting Supplement.

MicroGeophysics Corporation, 1995, Seismic hazard estimates for Denver Water Department facilities-1994; Seismological investigations in the Front Range by MicroGeophysics Corporation, 1977-1994, A summary report: unpublished report prepared for Denver Water Department, Denver, Colorado, 49 p.

Moore, J.E., Raynolds, R.G., and Barkmann, P.E., 2004, Groundwater mining of bedrock aquifers in the Denver Basin — past, present, and future: Environmental Geology, v. 63, p. 63-68.

Morgan, M.L., Temple, J., 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.

Nichols, D.J., 1994, A revised palynostratigraphic zonation of the nonmarine Upper Cretaceous, Rocky Mountain region, United States, *in* Caputo, M.V., Peterson, J.A., and Franczyk, K.J., eds., Mesozoic systems of the Rocky Mountain region: Denver, Rocky Mountain Section, Society for Sedimentary Geology (SEPM), p. 503-521.

Nichols, D.J., and Ott, H.L., 1978, Biostratigraphy and evolution of the *Momipites-Caryapollenites* lineage in the early Tertiary in the Wind River Basin, Wyoming: Palynology, v. 2, p. 93-112.

Noe, D.C., 1997, Heaving-bedrock hazards, mitigation, and land-use policy — Front Range piedmont, Colorado: Environmental Geosciences, v. 4, no. 2, p. 48-57.

Noe, D.C. and Dodson, M.D., 1999, Heaving-bedrock hazards associated with expansive, steeply dipping bedrock in Douglas County, Colorado: Colorado Geological Survey Special Publication 42, 80 p., 2 plates.

Noe, D.C., Jochim, C.L., and Rogers, W.P., 1997, A guide to swelling soils for Colorado homebuyers and homeowners: Colorado Geological Survey Special Publication 43.

Obradovich, J.D., 2002, Geochronology of Laramide synorogenic strata in the Denver Basin, Colorado: Rocky Mountain Geology, v. 37, p. 165-171.

Pepper, J.F., De Witt, W. Jr., and Demarest, D.F., 1954, Geology of the Bedford Shale and Berea Sandstone in the Appalachian basin: U.S. Geological Survey Professional Paper 259, 111 p.

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, 1997 RMS-AAPG Field Trip no. 7, p. 43-48.

Raynolds, R.G., 2002, Upper Cretaceous and Tertiary stratigraphy of the Denver Basin, Colorado: Rocky Mountain Geology, v. 37, no. 2, p. 111-134.

Raynolds, R.G., 2004, Stratigraphy and water levels in the Arapahoe aquifer, Douglas County area, Denver Basin, Colorado: The Mountain Geologist, v. 41, no. 4, p 195-210.

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: Rocky Mountain Geology, v. 38, no. 1, p. 171-181.

Richardson, G.B., 1916, Geologic atlas of the United States – Castle Rock folio, Colorado: U.S. Geological Survey Folio 198.

Robson, S.G., 1983, Hydrologic characteristics of the principal bedrock aquifers in the Denver Basin, Colorado: United States Geological Survey Hydrologic Investigations Atlas HA-659.

Robson, S.G., Van Slyke, G., and Graham, G., 1998, Structure, outcrop, and subcrop of the bedrock aquifers along the western margin of the Denver Basin, Colorado: U.S. Geological Survey Hydrologic Investigations Atlas HA-742, 5 sheets, scale 1:50,000.

Robson, S.G., and Romero, J.C., 1981a, Geologic structure, hydrology, and water quality of the Dawson aquifer in the Denver Basin, Colorado: U.S. Geological Survey Hydrologic Investigations Atlas HA-643, 3 sheets, scale 1:250,000.

Robson, S.G., and Romero, J.C., 1981b, Geologic structure, hydrology, and water quality of the Denver aquifer in the Denver Basin, Colorado: U.S. Geological Survey Hydrologic Investigations Atlas HA-646, 3 sheets, scale 1:250,000.

Robson, S.G., Romero, J. C., and Zawistowski, S., 1981a, Geologic structure, hydrology, and water quality of the Arapahoe aquifer in the Denver Basin, Colorado: U.S. Geological Survey Hydrologic Investigations Atlas HA-647, 3 sheets, scales 1:500,000 and 1:250,000.

Robson, S.G., Wacinski, A., Zawistowski, S., and Romero, J.C., 1981b, Geologic, structure, hydrology, and water quality of the Laramie-Fox Hills aquifer in the Denver Basin, Colorado: U.S. Geological Survey Hydrologic Investigations Atlas HA-646, 3 sheets, scale 1:500,000.

Rogers, W.P., Ladwig, L.R., Hornbaker, A.L., Schwochow, S.D., Hart, S.S., Sherton, D.C., Scroggs, D.L., and Soule, J.M., 1974, Guidelines and criteria for identification and land-use controls of geologic hazard and mineral resource areas: Colorado Geological Survey Special Publication 6, p. 36-43.

Schwochow, S. D., 1981, Inventory of nonmetallic mining and processing operations in Colorado: Colorado Geological Survey Map Series 17, 39 p., 17 pl., 1:250,000 scale.

Scott, G.R., 1962, Geology of the Littleton quadrangle, Jefferson, Douglas, and Arapahoe Counties, Colorado: U.S. Geological Survey, Bulletin 1121-L, scale 1:24000.

Scott, G.R., 1963a, Quaternary geology and geomorphic history of the Kassler quadrangle, Colorado: U.S. Geological Survey Professional Paper 421-A, scale 1:24000.

Scott, G.R., 1963b, Bedrock geology of the Kassler quadrangle, Colorado: U.S. Geological Survey Professional Paper 421-B, scale 1:24000.

Scott, G.R., and Lindvall, R.M., 1970 Geology of new occurrences of Pleistocene bisons and peccaries in Colorado: U.S. Geological Survey Professional Paper 700-B, p. B141-B149.

Scott, G.R., and Taylor, R.B., 1986, Map showing Late Eocene erosion surface, Oligocene-Miocene paleovalleys, and Tertiary deposits in the Pueblo, Denver, and Greeley 1° x 2° quadrangles, Colorado: U.S. Geological Survey Miscellaneous Investigations Series I-1626, 1:250,000, 1 sheet.

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

Selby, M.J., 1993, Hillslope Materials and Processes: Oxford University Press, Oxford, 451 p.

Shroba, R.R., 1977, Soil development in Quaternary tills, rock-glacier deposits, and taluses, southern and central Rocky Mountains: Boulder, University of Colorado, unpublished Ph.D thesis, 424 p.

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 in the Denver Basin: Denver, Rocky Mountain Association of Geologists Symposium, p. 231-235.

Steven, T.A., Evanoff, E., and Yuhas, R.H., 1997, Middle and Late Cenozoic tectonic and geomorphic development of the Front Range of Colorado, *in* Boylard, D.W., and Sonnenberg, S.A, eds., Geologic history of the Colorado Front Range: RMS-AAPG Field Trip 7, Rocky Mountain Association of Geologists, p. 115-134.

Szabo, B.J., 1980, Results and assessment of uranium-series dating of vertebrate fossils from Quaternary alluviums in Colorado: Arctic and Alpine Research, v. 12, no. 1, p. 95-100.

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 04-05, scale 1:24,000.

Thorson, J.P., 2004b, Geologic map of the Cherry Valley School quadrangle, Douglas 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 05-2, scale 1:24,000.

Thorson, J.P., 2005b, Geologic map of the Larkspur quadrangle, Douglas County, Colorado: Colorado Geological Survey Open-File Report 05-7, scale 1:24,000.

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 02-4, scale 1:24,000.

Topper, R, Spray, K.L., Bellis, W.H., Hamilton, J.L., and Barkmann, P.E., 2003, Ground-Water Atlas of Colorado: Colorado Geological Survey Special Publication 53, 210 p.

Trimble, D.E., and Machette, M.N., 1979, Geologic map of the Colorado Springs-Castle Rock area, Front Range Urban Corridor, Colorado: U.S. Geological Survey Miscellaneous Investigations Series I-857-F.

Tweto, O., 1975, Laramide (Late Cretaceous—early Tertiary) orogeny in the southern Rocky Mountains, *in* Curtis, B.F., ed., Cenozoic history of the southern Rocky Mountains: Geological Society of America Memoir 144, p. 1-44.

VanSlyke, G., 2004, Water levels in the Denver Basin bedrock aquifers, October 2004: Colorado Division of Water Resources, Office of the State Engineer.

Widmann, B. L., Kirkham, R. M., Morgan, M. L., and Rogers, W. P., *with contributions by* Crone, A. J., Personius, S. F., and Kelson, K. I., *and GIS and Web design by* Morgan, K. S., Pattyn, G. R., and Phillips, R. C., 2002, Colorado Late Cenozoic fault and fold database and Internet map server: Colorado Geological Survey Information Series 60a, http://geosurvey.state.co.us/pubs/ceno/.

Woodburne, M.O., and Swisher, C.C., III, 1995, Land mammal high-resolution geochronology, intercontinental overland dispersals, sea level, climate and vicariance in Berggren, W.A., Kent, D.V., Aubry, M-P., and Hardenbol, J., eds., Geochronology time scales and global stratigraphic correlation: Tulsa, Society of Sedimentary Geology Special Publication 54, p. 335-364.

Wray, L.L., Apeland, A.D., Hembord, H.T., and Brchan, C.A., 2002, Oil and gas fields map of Colorado: Colorado Geological Survey Map Series 33, scale 1:500,000.