OPEN-FILE REPORT 02-4

Geologic Map of the Monument Quadrangle, El Paso County, Colorado

By Jon P. Thorson and Richard F. Madole

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RECLAMATION•MINING SAFETY•SCIENCE

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FOREWORD

The Colorado Department of Natural Resources is pleased to present the Colorado Geological Survey Open File Report 02-4, *Geologic Map of the Monument Quadrangle, El Paso County, Colorado.* Its purpose is to describe the geologic setting and mineral resource potential of this 7.5-minute quadrangle located near the northern edge of the Colorado Springs metropolitan area.

Jon Thorson and Richard Madole completed the field work on this project in the summer of 2000.

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, Agreement No. 00HQAG0119, and the Colorado Geological Survey (CGS) using the Colorado Department of Natural Resources Severance Tax Operational Funds. The CGS matching funds come from the Severance Tax paid on the production of natural gas, oil, coal, and metals.

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George D. Vanslyke, Colorado Division of Water Resources, provided generous access to his agency's files of water-well logs. Jane Ciener served as technical editor. James Messerich set photogrammetric models on a Kern PG-2 plotter.

This project benefited from discussions with Glenn Scott, John Himmelreich, Jon Lovekin, Michael Machette, Dave Noe, and George Vanslyke. Special thanks go to the landowners and developers who granted permission to enter their property.

INTRODUCTION

The Monument 7.5-minute quadrangle is located near the northern edge of the Colorado Springs metropolitan area, which is in the southern part of the Colorado Piedmont section of the Great Plains (Figure 1). This section of the Great Plains is distinguished by having been stripped of the Miocene fluvial rocks (Ogallala Formation) that cover most of the Great Plains. Some middle Cenozoic rocks, the Castle Rock Conglomerate and Wall Mountain Tuff, also have been eroded from the Monument quadrangle, although erosional remnants are present a few miles to the north. The Monument quadrangle lies mostly in the drainage basin of Monument Creek, although in the northeastern quarter it reaches over

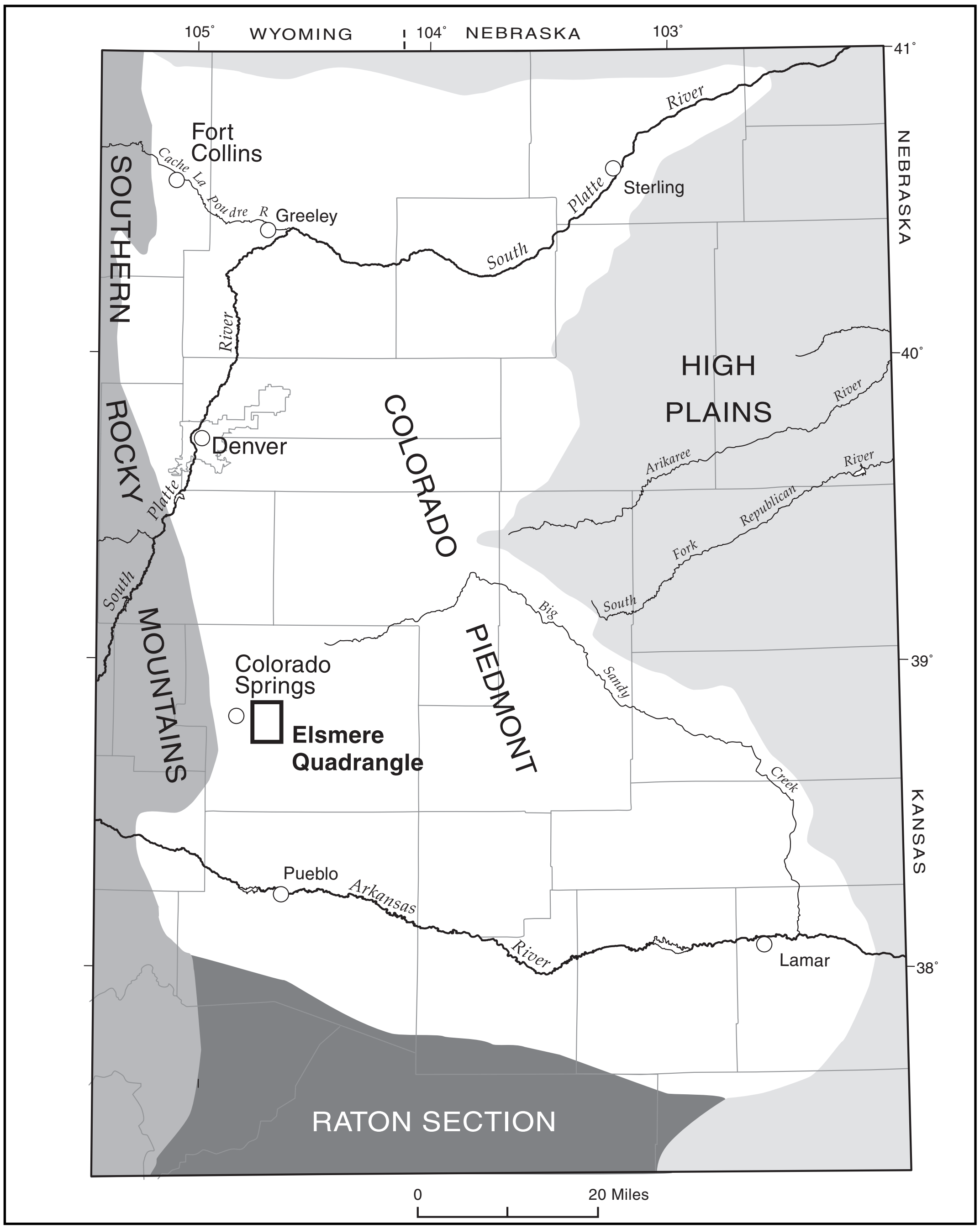

Figure 1. Map showing the location of the Monument quadrangle with respect to the Southern Rocky Mountains and the Colorado Piedmont, High Plains, and Raton sections of the Great Plains (modified from Madole, 1991; physiographic nomenclature from Fenneman, 1931).

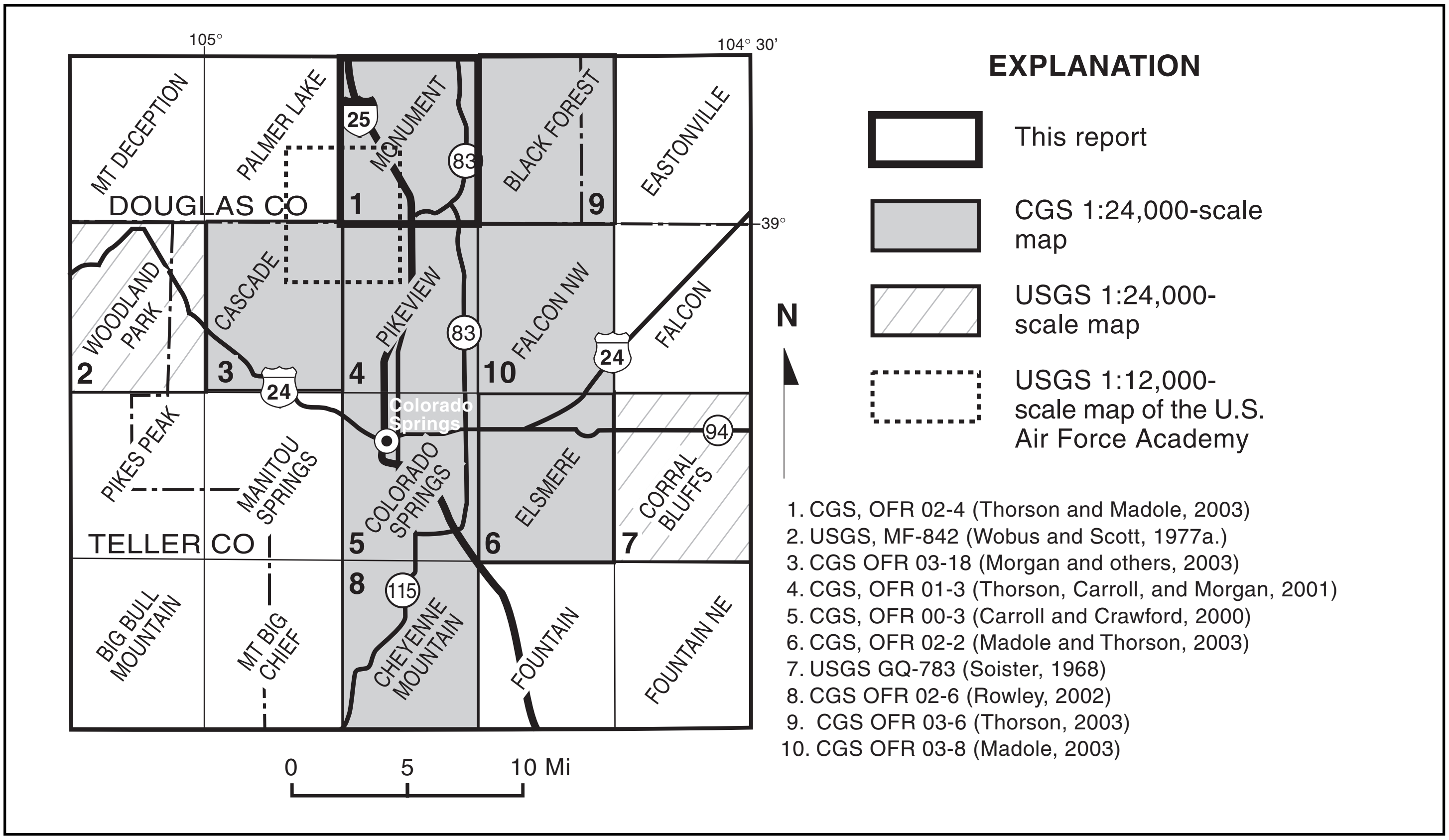

Figure 2. Index map showing the location of the Monument quadrangle and other geologic maps in the area published at a scale of 1:24,000 and 1:12,000.

the Palmer Divide, the interfluve between the South Platte and Arkansas Rivers. Most of the surficial deposits of the quadrangle can be related to the development of Monument Creek. However, on the divide and extending northeast into the head of Cherry Creek, an older alluvial deposit pre-dates the development of Monument Creek.

Geologic mapping of the Monument 7.5-minute quadrangle was undertaken by the Colorado Geological Survey (CGS) as part of the STATEMAP component of the National Cooperative Geologic Mapping Program. Geologic maps produced by the CGS through the STATEMAP program are intended as multi-purpose maps useful for land-use planning, geotechnical engineering, geologic-hazards assessment, mineral-resource development, and groundwater evaluation. Figure 2 shows the status of geologic mapping of 7.5-minute quadrangles in the Colorado Springs area.

This map was based on prior published and unpublished geologic maps and reports, interpretation of aerial photography, and field investigations in 2001 and 2002. Mapping of some of the more heavily urbanized parts of the quadrangle was extrapolated from compilation and reconnaissance mapping by Trimble and Machette (1979a). Previous geological mapping in the Colorado Springs area includes the work of Emmons and others (1896) and Finlay (1916). Varnes and Scott (1967) mapped part of the quadrangle that is now the United States Air Force Academy at a scale of 1:12000; some of their work has been modified and incorporated into this map. Scott and Wobus (1973) mapped the Colorado Springs area, which is just south of the Monument quadrangle, in reconnaissance fashion and published a geological map at a scale of 1:62,500.

Responsibility for mapping surficial geology and bedrock geology and authorship of those parts of this report that deal with these subjects were divided between the two authors. Thorson mapped and described the bedrock geology, alluvium of Palmer Divide, and a few of the surficial deposits in the Monument Creek valley. Madole mapped and described most of the surficial deposits.

GEOLOGIC SETTING

The Monument quadrangle is located near the western edge of an asymmetrical, oval-shaped, structural depression called the Denver Basin (Emmons and others, 1896). This structural basin lies immediately east of the Front Range and covers most of eastern Colorado north of Pueblo, southeastern Wyoming, and southwestern Nebraska. Bedrock in the Monument quadrangle dips gently northeast toward the axis of this basin.

The oldest rocks in the Monument quadrangle are the assemblage of lithologies shown on the geological map as facies unit one of the upper part of the Dawson Formation ($TKda_1$). At the time of deposition of this unit during the early Paleocene (about 66 million years ago) the uplift of the Front Range was well underway. Energetic braided streams were delivering to the basin a mixture of coarse gravel, sand, and finer silt and clay derived from weathering and erosion mostly of the Precambrian Pikes Peak Granite. The source area for these granitic arkosic materials was immediately to the west across the mountain-front fault system called the Rampart Range Fault. Stream flow was generally towards the east. The pebble conglomerate and arkosic sand beds of unit $TKda_1$ are cross-bedded and fill broad channels generally cut into finer-grained deposits of clayey sandstones and sandy claystones. Interbedded with the thick channel deposits are occasional massive structureless beds deposited by mudflows that commonly contain small fragments of charcoal. The mudflow beds and charcoal in facies unit one indicate that the paleotopographic slope was relatively steep and that occasional forest fires burned parts of the source area. Interbedded between the coarse-grained beds in facies unit one are finer-grained and thinner-bedded strata of light gray clayey sandstones and brown or brownish gray sandy claystones containing fragments of organic material and plant fossils. The fine-grained parts of facies one were deposited by gentler currents in areas between the braided stream channels and probably were covered with vegetation.

At the same time facies unit one of the upper Dawson was being deposited on the steeper parts of an east-sloping complex of alluvial fans along the mountain front, upper Dawson facies unit three ($TKda_3$) was being deposited to the northeast on the lower slopes of the fans and on the floor of the basin. Facies unit three is similar to facies unit one, but is finer grained and has less coarse-grained light colored arkoses and a greater proportion of fine sandstones and greenish gray to grayish green claystone beds.

In the center of the west edge of the quadrangle the interfingering of facies units one and three ($TKda_1$ and $TKda_3$) extends to the western edge of the quadrangle. At this time facies unit three, which accumulated in a lower-energy environment than facies unit one, was being deposited closer to the basin margin than at any other time. The higher-energy facies unit one was being deposited only very near the basin-bounding range front fault. This geometry indicates that only a limited amount of coarse arkosic material was being delivered to the basin, which suggests the uplift rate of the Front Range was lower during this time interval.

After this period of reduced tectonic activity, the uplift appears to have accelerated again with the deposition of facies unit four ($TKda_4$). Facies unit four is lithologically similar to facies unit one in that it is dominated by very thick beds of light colored, coarse-grained arkosic material deposited by energetic braided streams that rapidly extended out into the basin. A long period of landscape stability then occurred (perhaps as much as 9 million years, Raynolds, personal commun., 2001) and resulted in a strongly developed paleosol horizon intermittently exposed across the quadrangle. This strongly developed paleosol was found to be the boundary between the Paleocene and Eocene epochs in the region by Soister and Tschudy (1978). In this work the projected location of the strongly developed paleosol has been used as the boundary between facies units four and five.

After this period of landscape stability, uplift resumed and facies unit five ($TKda_5$) was deposited. Facies unit five is lithologically similar to facies units one and four in that it is dominated by very thick beds of light colored, coarse-grained arkosic material deposited by energetic braided streams.

The upper part of the Dawson Formation was removed by an extended period of erosion that last-ed about 15 million years. The latest Eocene Wall Mountain Tuff (McIntosh and Chapin, 1994) and early Oligocene Castle Rock Conglomerate were deposited on an erosion surface cut into the upper Dawson strata. Since the deposition of these middle Tertiary rocks, the area experienced multiple periods of erosion and deposition. During the Miocene the Ogallala Formation was deposited across much of eastern Colorado and probably once covered the quadrangle but has since been removed by erosion. During the Quaternary, deposits of unconsolidated sands and gravels were left in channels and flood plains along stream courses and on various upland erosion surfaces as the streams eroded and incised into the landscape

SURFICIAL GEOLOGY

The names and symbols used for surficial units in the Monument quadrangle conform as much as possible to those employed previously on geologic maps of nearby areas prepared by the Colorado Geological Survey (Figure 2). Map units were delineated mainly by airphoto interpretation that was verified and supplemented with data collected along traverses on the ground and from fieldwork in selected areas. A pocket stereoscope was used to delineate map units on aerial photographs while in the field. Later, map unit contacts were transferred to a topographic map of the Monument quadrangle by tracing contacts from copies of aerial photographs that were enlarged or reduced to match the map scale.

The scale of the base map and aerial photographs governed the minimum size of the deposits shown. With few exceptions, deposits that have minimum dimensions of less than 150 ft were not mapped. Also, deposits that are less than 5 ft thick were not mapped unless they are coincident with landforms that can be delineated on aerial photography. In order to study the landscape that existed prior to urbanization, it was necessary to use three different generations of aerial photography. The type, dates, and scales of the photography used are (1) black and white, October 1969, 1:28,000, (2) color infrared, August 1988, 1:40,000, and (3) black and white, April 1992, 1:24,000. The 1969 and 1992 photographs were relied on the most. The topographic base map was published in 1986. Thus, roads, reservoirs, and buildings that were constructed after 1986 are not on the map, and human-made deposits that postdate the 1992 aerial photography may not be on the map.

The surficial deposits of the Monument quadrangle are not well exposed. Consequently, the thickness of most units is estimated and descriptions of physical characteristics such as texture, stratification, and composition are based on observations at a small number of localities. Particle size is expressed in terms of the modified Wentworth scale (Ingram, 1989), and the terms used to describe sorting (a measure of the range in particle sizes present) are those of Folk and Ward (1957). Except for windblown deposits, all surficial deposits in the Monument quadrangle are poorly sorted to extremely poorly sorted.

In the modified Wentworth scale, gravel includes pebbles, cobbles, and boulders. Also, because gravel has the connotation of rounded rock fragments (Bates and Jackson, 1995), angular rock fragments larger than 0.0833 in. (2 mm) are referred to as pebble size or cobble size, as the case may be. Clast, as used here, is limited to rock fragments (rounded or angular) that are larger than 0.0833 in. (2 mm) in maximum dimension, and matrix refers to fragments that are smaller than 0.0833 in. (in other words, sand-, silt-, and clay-size particles). The colors of surficial map units were determined using Munsell Soil Color charts (Munsell Color, 1973) and are for dry materials only. The Munsell designations of hue, chroma, and value for these colors are listed in Table 1.

The sidereal age limits adopted for early, middle, and late Pleistocene time (see Quaternary time chart on map) are 1,806–778 ka (kilo-annum, 10^3 yr), 778–127 ka, and 127–11.5 ka, respectively. The date for the Pliocene–Pleistocene boundary, 1.806 Ma (Mega-annum, 10^6 yr), is the astronomically tuned age calculated by Lourens and others (1996). The 11.5 ka date for the Pleistocene–Holocene boundary is approximately the calibrated equivalent of 10,000

Table 1. Sediment colors and corresponding Munsell Soil Color Chart notations.

Unit color	Hue, Value, and Chroma
strong brown	7.5YR5/6
very dark grayish brown	10YR3/2
dark grayish brown	10YR4/2
grayish brown	10YR5/2
brown	10YR5/3
yellowish brown	10YR5/4
light brownish gray	10 YR6/2
pale brown	10YR6/3
light yellowish brown	10YR6/4
very pale brown	10YR7/3 and 8/3

radiocarbon years, the date proposed in 1969 for this boundary by the INQUA Commission for the Study of the Holocene (Farrand, 1990). The boundary between the early and middle Pleistocene is the time of the Matuyama-Brunhes magnetic reversal, which occurred about 778 ka (Tauxe and others, 1992). The boundary between oxygen-isotope ($^{18}O/^{16}O$) stage 6 and stage 5 is the boundary between middle and late Pleistocene time. Bassinot and others (1994) place the isotope stage 6–stage 5 boundary at 127 ka, which is a refinement of the 128 ka date calculated by Imbrie and others (1984).

The age limits used here for divisions of the Holocene are informal and arbitrary. They are based chiefly on paleontological data compiled for the southwestern United States, including the Colorado Plateau, such as described by Van Devender and others (1987). The data define times of widespread climatically driven shifts in the limits of vegetation associations, changes in lake levels and chemistry, and so forth. However, some changes may be time-transgressive and some records are imperfectly dated. Holocene chronostratigraphy is a work in progress and informal divisions of the epoch are not well defined. The age limits used for early, middle, and late Holocene are 11.5–8 ka, 8–4 ka, and 4–0 ka, respectively.

The ages assigned to the surficial deposits of the Monument quadrangle are estimates that are based chiefly on stratigraphic relations and positions in the landscape. Ordinarily, differences in degree of soil-profile development play a major role in determining the relative ages of surficial deposits, but this is not true for much of the Monument quadrangle. Degree of soil development refers to attributes such as profile thickness, horizon complexity, soil structure, quantities of translocated clay or calcium carbonate present, depth of leaching, and so forth. On stable surfaces (those not significantly modified by either erosion or deposition), soil development produces more complex and generally thicker horizon sequences with time, proceeding from thin, simple A/C profiles to more complex, thicker A/B/C profiles (Figure 3).

Over much of the Monument quadrangle, the soils in surficial deposits are very weakly developed (that is, they lack even a rudimentary B horizon) regardless of the age of the deposit in which the soil is developed. Pring soils (Larsen, 1981), which typically have of an A/AC/C horizon sequence, are the most widespread series developed in surficial deposits, especially east of Monument Creek. They are developed in stream-terrace deposits and piedmont-slope deposits that span the full range of middle and late Pleistocene time (778–11.5 ka).

Soils of the Tomah series (Larsen, 1981) also are developed in places in piedmont-slope deposits, most notably over broad areas south of Dirty Women Creek in the northern part of map area. The typical Tomah soil profile consists of an A/E/Bt/C horizon sequence. The combined thickness of the A, E (zone of eluviation), and B horizons is about 4 ft, and the Bt horizon (zone of clay enrichment) is about 2 ft thick. Clearly, the Tomah soils are more strongly developed than are the Pring soils. In many respects, Tomah soils are similar to soils developed in deposits of middle Pleistocene age elsewhere in the Colorado Piedmont (for example, the Louviers and Slocum Alluviums, Figures 3 and 4).

It should be noted that the Tomah and Pring soils in the area between Dirty Women and Jackson Creeks are developed in piedmont-slope deposits that appear to be of the same age. The Pring soils must be much younger than the deposits in which they are developed. One explanation for this apparent anomaly is that in the areas of the Pring series sheet flow and deflation have eroded older soils. Presumably, these soils either did not contain much clay or did not survive long enough to accumulate clay or $CaCO_3$ in quantities great enough to make the soils more resistant to erosion.

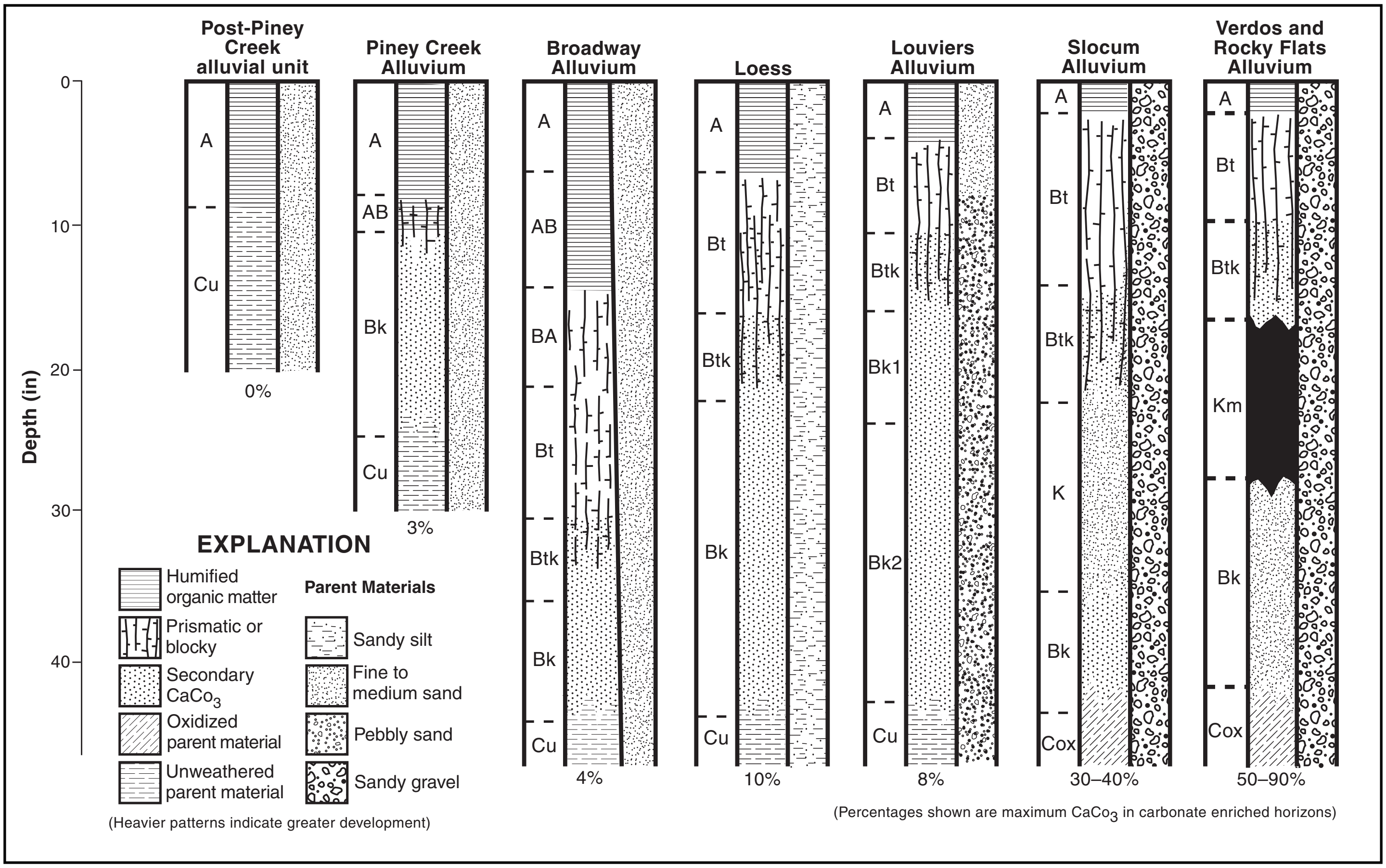

Figure 3. Diagram illustrating progressive increase (left to right) in degree of soil development with increased age in the Lafayette quadrangle, which is just north of Denver. See Figure 4 for stratigraphic positions of alluvial units. Diagram is from Machette (1977), modified slightly by Madole (1991) to reflect changes in soil-horizon designations adopted in the 1980s (Guthrie and Witty, 1982, and Soil Survey Division Staff, 1993).

ALLUVIUM OF PALMER DIVIDE

On Palmer Divide and in the upper part of the Cherry Creek drainage, deposits of sand and gravel may be remnants of an abandoned paleodrainage system of ancestral Cherry Creek. A paleochannel deposit on the divide suggests that Monument Creek has eroded headward and captured the former headwaters of Cherry Creek. Clast lithology, deposit geometry, and position in the landscape suggest that deposits of the alluvium of Palmer Divide (unit QTa), along with the erosion surfaces on which they rest, are older than the early (?) Pleistocene deposits in the Monument Creek drainage (units Qg_3 and Qas_3) and thus may be early Pleistocene or late Pliocene.

One of the deposits of unit QTa (sec. 20, T. 11 S., R. 66 W.) was mapped in part as Pleistocene age Nussbaum Alluvium by Trimble and Machette (1979a). The age of the Nussbaum Alluvium has been the subject of considerable debate. Scott (1963c), who argued for a Pleistocene age, gave a review of the history that will not be repeated here. Nussbaum Alluvium has also been considered to be mostly Pliocene but may include early Pleistocene (Scott, 1982; Madole, 1991). Soister (1967) discussed occurrences of Nussbaum Alluvium in the Monument area but did not identify the deposit in sec. 20 as Nussbaum. Soister's maps of the projected elevations of Nussbaum deposits indicate the elevation of the Nussbaum on the Palmer Divide, east of the town of Monument, could be about 7,500 ft. The elevation of the highest remaining deposit of unit QTa is about 7,500 ft, but the QTa deposits slope northeastward into the Cherry Creek drainage to an elevation of about 7280 ft near the northeast corner of the quadrangle. Some of the remnants of unit Qta were previously mapped as Slocum Alluvium by Trimble and

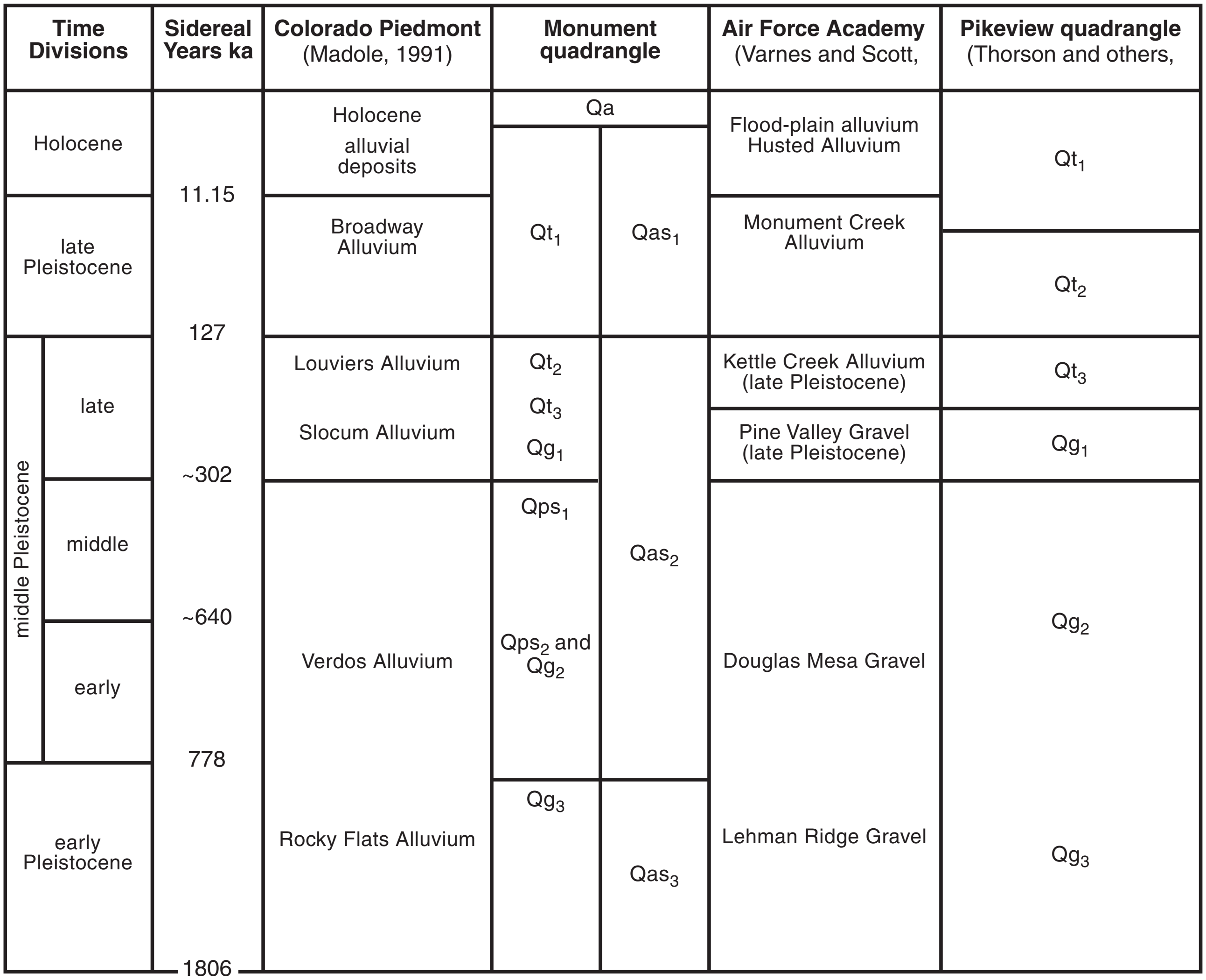

Figure 4. Diagram showing how the principal alluvial units in the Monument and Pikeview quadrangles correlate with the regional alluvial stratigraphy of the Colorado Piedmont. Time divisions are from Madole (1991) and correspond approximately with those of the Quaternary time chart on the map. Most of the ages initially assigned to the alluvial units in the Colorado Piedmont (Scott, 1963; Varnes and Scott, 1967; Scott and Wobus, 1973) have changed. The time terms in parentheses for the Kettle Creek Alluvium and Pine Valley Gravel are the ages initially assigned by Varnes and Scott (1967).

Machette (1979a), which is somewhat younger in age than the Nussbaum (Figure 4).

Most of the surficial units in the quadrangle were deposited on surfaces that slope toward Monument Creek or toward tributaries of Monument Creek. Thus, they record the history of changing base levels as Monument Creek eroded deeper. The granitic gravel deposits (units Qg_3, Qg_2, and Qg_1), which were deposited on eastward-sloping surfaces west of Monument Creek, contain boulders and cobbles of pink to reddish brown Pikes Peak Granite eroded from the Rampart Range to the west. These granite cobbles and boulders were reworked and deposited in channels and on flood plains that subsequently became terraces (units Qt_3, Qt_2 and Qt_1) as Monument Creek continued to deepen its valley. On the east side of Monument Creek, the upland surfaces are mantled by very pale brown to brown sand and gravel deposits which have been derived from arkoses in the underlying Dawson Formation. While the Dawson Formation was largely derived from an earlier episode of erosion of the granites of the Rampart Range, in the Monument quadrangle the Dawson Formation contains no boulder-sized clasts, but rather only small cobbles with diameters up to about 3 in. These coarser clasts are usually found in parts of the quadrangle closest to their mountain front source, on the west side of Monument Creek and in the northwest corner of the map area. The finer grain size of the west-sloping surficial deposits on the east side of Monument Creek is limited by the small grain sizes available in the underlying bedrock. Thus, larger cobbles and boulders of pink to reddish brown granite are diagnostic of deposits from streams which drain the Rampart Range. Boulders of Pikes Peak Granite in the alluvium of Palmer Divide cannot have been eroded from the Dawson Formation east of Monument Creek.

Cobbles and boulders of Pikes Peak Granite on the northeast side of the Palmer Divide might have been derived from reworking older Tertiary deposits that formerly cropped out in the area. Older gravel deposits of Oligocene (?) to Pliocene age that contain granite clasts were mapped in the Rampart Range by Trimble and Machette (1979a). The Oligocene-age Castle Rock Conglomerate contains clasts of Pikes Peak Granite in some localities. Erosional remnants of the Castle Rock Conglomerate occur a few miles to the north of the quadrangle. The Miocene-age Ogallala Formation, which underlies much of the high plains of eastern Colorado, also was probably once present in the quadrangle. In eastern Colorado the Ogallala contains pebble gravel; closer to the Front Range it may have contained much coarser deposits.

In the exposures of unit QTa on the west side of the divide, cobble and boulder gravel is interbedded with beds of pebble gravel and sand. The cobble and boulder gravels are composed of (1) round to subround clasts of Pikes Peak Granite, (2) subround buff to brown clasts of weathered Dawson Formation arkose, (3) subangular to subround clasts of white or light gray quartz, and (4) angular to subangular gray or light brownish gray welded tuff that resembles the Wall Mountain Tuff. Matrix between the cobble and boulder gravel clasts is chiefly gray sand. Sand and pebble-gravel beds, which are interbedded with the coarser gravels, have sedimentary structures characteristic of fluvial deposits and cross bedding that is inclined towards the northeast, suggesting northeast-directed paleocurrents.

The finer-grained parts of the alluvium of Palmer Divide (QTa) are variable; they are generally composed of pale brown and light brown, fine to coarse sand interbedded with pinkish gray to light brownish gray pebble gravel. The sand is poorly sorted, medium to thin bedded, thinly laminated, and composed largely of quartz grains. The sands exhibit bedding and lamination features characteristic of fluvial deposition. The pebble gravel is composed largely of subangular to subround fragments of white or light gray quartz, light pink to light red and reddish brown feldspar, and fragments of pink to light red granite. The pebble gravel occurs in thick massive beds and as thin beds, small lenses, and laminae in fluvial sand. Weathered and deflated surfaces of these deposits are covered with a lag of subround pebbles in which white quartz pebbles stand out prominently.

In the QTa deposit in SE1/4 sec. 6, T. 11 S., R. 66 W., a lag deposit of cobbles and boulders of Dawson arkose, Pikes Peak Granite, white quartz, and gray welded tuff rests on weathered Dawson Formation and is overlain by light brown alluvial sand. Cobble-size clasts of white quartz and reddish granite are common on the surface near the edges of the finer-grained deposits of this unit. These clasts are float that can not have come from the underlying Dawson Formation; they indicate that a lag deposit of cobbles and boulders commonly occurs along the erosion surface between the Dawson and the overlying alluvium.

The following factors suggest that unit QTa is either the oldest Pleistocene deposit in the quadrangle or possibly a Pliocene-age deposit.

1. The cobble and boulder gravels and the lag deposits containing clasts of Pikes Peak Granite cannot have been derived from the underlying Dawson Formation.
2. The cobble and boulder gravels on the divide are about 3 mi. east of, and 800 ft higher than, the closest Quaternary deposits along Monument Creek that contain cobbles and boulders of Pikes Peak Granite. They are about 200 ft higher than the western, upper edges of the higher level early (?) and middle Pleistocene age granitic gravel deposits (units Qg_2 and Qg_3) on the west side of Monument Creek.
3. The cobble and boulder gravels on the divide are interbedded with sand and pebble gravel beds containing sedimentary structures that indicate fluvial deposition and with inclined bedding that indicates northeast-directed paleocurrents. The coarse gravels and interbedded finer- grained deposits on the Palmer

Divide are incised into the underlying Dawson Formation in a paleochannel.

4. Cobbles and boulders originally derived from the Pikes Peak Granite are now separated from their source area in the Rampart Range by the present topography of Monument Creek across which they must have been transported, before Monument Creek had eroded headward to its present extent. This transport could have happened through the reworking of older Tertiary deposits, or directly in a late Pliocene to early Pleistocene drainage.
5. The cobble and boulder gravels and lag deposits contain angular to subangular fragments of latest Eocene age Wall Mountain Tuff (36.73 ± 0.07 Ma., McIntosh and Chapin, 1994). These clasts set a maximum age for the unit.
6. The Wall Mountain Tuff was erupted onto an eastward-sloping, low relief, Eocene erosion surface (Scott and Taylor, 1986). The nearest remnant of the the Wall Mountain Tuff is located on Bald Mountain, which is on the Greenland quadrangle about 5 mi. north–northwest of the cobble and boulder gravels on Palmer Divide. The Bald Mountain exposure is about 300 ft higher in elevation than the cobble and boulder gravels on Palmer Divide indicating that a significant amount of post-Eocene erosion occurred between the eruption of the tuff and the deposition of the gravels. This relationship suggests that the Eocene surface was considerably higher in elevation than the erosion surface beneath the alluvium of Palmer Divide. The Oligocene-age Castle Rock Conglomerate was deposited during reworking of the Eocene erosion surface and overlies the tuff in places. The Oligocene erosion surface was significantly higher in elevation than the alluvium of Palmer Divide.

The alluvium of Palmer Divide is probably part of a dismembered paleovalley system younger than Oligocene in age, and possibly as young as early Pleistocene. The possible Pliocene age for this unit is consistent with the Trimble and Machette's (1979a) correlation of parts of this deposit with the Nussbaum Alluvium which is currently considered to be Pliocene in age (Scott, 1982). Thus, the QTa deposits are remnants of a paleodrainage system that contained deposits of Nussbaum Alluvium or alluvium reworked from the Nussbaum. This paleovalley may have connected the present Cherry Creek drainage to its original headwaters in the Rampart Range. Monument Creek eroded headward and captured the headwaters of Cherry Creek, leaving the paleochannel abandoned on the divide.

BEDROCK GEOLOGY

The bedrock geology of the Monument quadrangle was mapped on aerial photographs and transferred to the topographic base map on a Kern PG-2 plotter. Two sets of aerial photographs were used; black and white, 1:24,000-scale photography flown in 1992, and color infrared, 1:40,000-scale aerial photography flown in 1988. The texture, sorting, and grain size classifications used for bedrock deposits are the same as those described for the surficial deposits. Color descriptions of bedrock lithologies were described from surfaces that were damp or wet.

NOMENCLATURE OF THE DAWSON FORMATION

The sedimentary rocks lying above the Laramie Formation were first called Dawson "arkose" (with a lower case "a") by Richardson (1912) from a type locality on Dawson Butte near the town of Castle Rock, about 10 mi. northwest of the Monument quadrangle. Richardson (1915, Figure 3) showed the Dawson "arkose" of the Castle Rock area as equivalent to, and interfingering with, the Arapahoe and Denver Formations of the Denver area. Finlay (1916) recognized that the Dawson "arkose" extended into the Colorado Springs area and contained an andesitic sandstone unit at the base. Varnes and Scott (1967) used the name Dawson Arkose (upper case "A") and recognized that there are two "beds of andesitic material" in the area south and east of the U.S. Air Force Academy. Scott and Wobus (1973) changed the name to Dawson Formation, in recognition that the unit was not entirely composed of arkose; they mapped a lower part (andesitic) and upper part of the Dawson Formation. In the Pikeview quadrangle Thorson and others (2001) mapped three informal members in the upper part of the Dawson Formation (Figure 5) that Scott and Wobus (1973) described but did not map separately. In the study five informal members are recognized. The nomenclature used in our description for the Dawson Formation follows that of Scott and Wobus (1973) and Trimble and Machette (1979a) in referring to Dawson Formation rather than Dawson Arkose. The use of the symbol "TKda" for the upper part of the Dawson Formation follows the usage of Trimble and Machette (1979a).

FACIES OF THE UPPER DAWSON FORMATION

The upper part of the Dawson Formation consists of five facies units in the Colorado Springs area: facies unit one ($TKda_1$), facies unit two ($TKda_2$), facies unit three ($TKda_3$), facies unit four ($TKda_4$), and facies unit five ($TKda_5$). Figure 6 diagrammatically shows the regional relationships between these units. Facies unit one occurs in part as a very thick "basin edge" deposit close to the mountain front on the western edge of the basin in the Pikeview and Monument quadrangles. Facies one also occurs as a coarse basal unit of the upper Dawson, beneath finer-grained facies, that crops out from the Pikeview quadrangle southeastward into the Elsmere quadrangle (Madole and Thorson, 2002). Finer-grained basinal facies units two and three interfinger with and overlie the coarser mountain front and basal facies unit one. Facies unit two does not crop out in the Monument quadrangle, but it occurs in the subsurface on the basis of projections from the Pikeview quadrangle and from drill hole data. In the Monument quadrangle, facies units four and five, dominated by light colored arkoses, were deposited over the top of the finer-grained facies unit three. Contacts between facies units within the basin are both gradational and interfingering. Erosion has removed the uppermost part of facies unit four in the Monument quadrangle.

The relationship of the Dawson Formation subdivisions of the Colorado Springs area to the stratigraphy used in the Denver area is uncertain. Trimble and Machette (1979b) summarized the current usage of Arapahoe, Denver, and Dawson Formations (in ascending order) for the greater Denver area (Figure 7). The Arapahoe and Dawson Formations consist of arkosic sandstone, siltstone, claystone, and minor amounts of conglomerate. Where this arkosic and conglomeratic lithology underlies the Denver Formation it is called the Arapahoe Formation. The Denver Formation consists of claystone, siltstone, sandstone, and conglomerate composed primarily of altered andesitic volcanic debris. The Denver Formation pinches out to the south and east. Beyond the pinchout, all the strata equivalent to the Arapahoe and Denver Formation are included in the Dawson Formation.

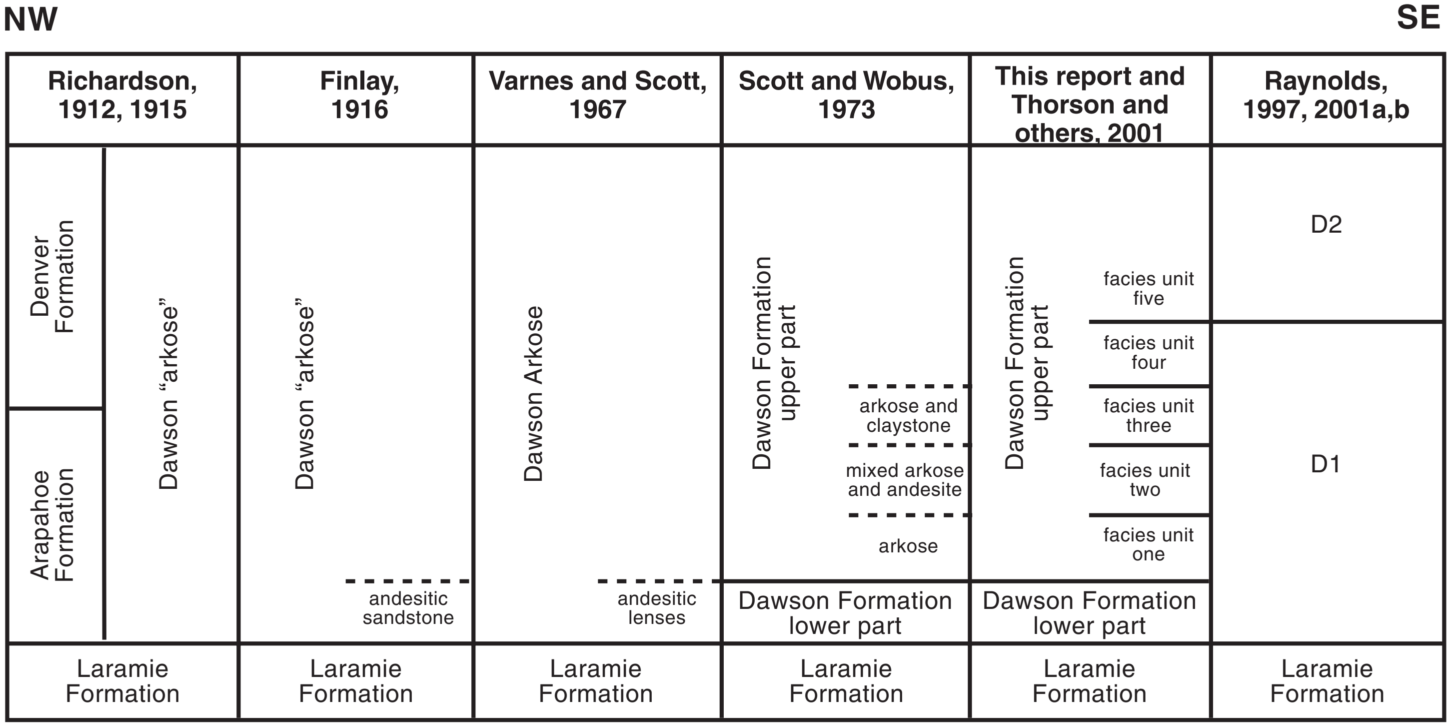

Figure 5. Nomenclature diagram for subdivisions of the Dawson Formation as used in various publications pertaining to the Colorado Springs area.

The interfingering of the Denver Formation with the Dawson Formation, and the pinchout of the Denver Formation to the southeast, has been mapped along the southern edge of the Denver metropolitan area. Scott (1962, p. L19–L20) described apparent interfingering of the Denver Formation with the Dawson “arkose” in the Littleton quadrangle and concluded that “southward they (andesitic beds) probably dwindle to a thin tongue in the Dawson arkose”. In the Kassler quadrangle Scott (1963b) retained the usage Dawson “arkose” for the whole unit and did not find a mappable unit dominated by andesitic debris. Maberry and Lindvall (1972, 1977) mapped an upper tongue of Denver Formation that inter-fingers with the Dawson Arkose (Figure 7) in the Parker and Highlands Ranch quadrangles. Trimble and Machette (1979b) summarized this relationship and changed the formation name from Dawson Arkose to Dawson Formation.

However, it is common usage in the Colorado Springs area to map the andesite- bearing facies unit, here mapped as upper Dawson Formation facies unit two, as the Denver Formation (John Himmelreich, Jr., oral commun., 2000). This correlation has largely come about through the use of the Denver-area formation names (Arapahoe, Denver, and Dawson) for regional aquifer units that have been extended throughout the hydrologic Denver Basin (see for example, Robson, 1987). The extension of the Denver-area formation nomenclature throughout the Denver Basin was accomplished largely by correlating geophysical log signatures of hydrologic units in water and oil wells. Unfortunately, the hydrologic units do not correlate precisely with the mappable geologic units exposed at the surface (George Vanslyke, oral commun., 2000). The geophysical logs used for this correlation can separate porous and permeable sandstones and conglomerates from “tight” shales and claystones, but they can not reveal the lithologies of the sandstones and pebble conglomerates. The geologic units mapped at the surface are based on lithological criteria, largely the presence or absence of andesitic debris, a distinction which can not be made from geophysical logs from wells. Thus, the extension of the Denver Formation to Colorado Springs remains suspect, especially since Scott (1962, 1963b), Maberry and Lindvall (1972, 1977), and Trimble and Machette (1979b) described the Denver Formation as intertonguing with the Dawson Formation and pinching out towards the south and east. Furthermore,

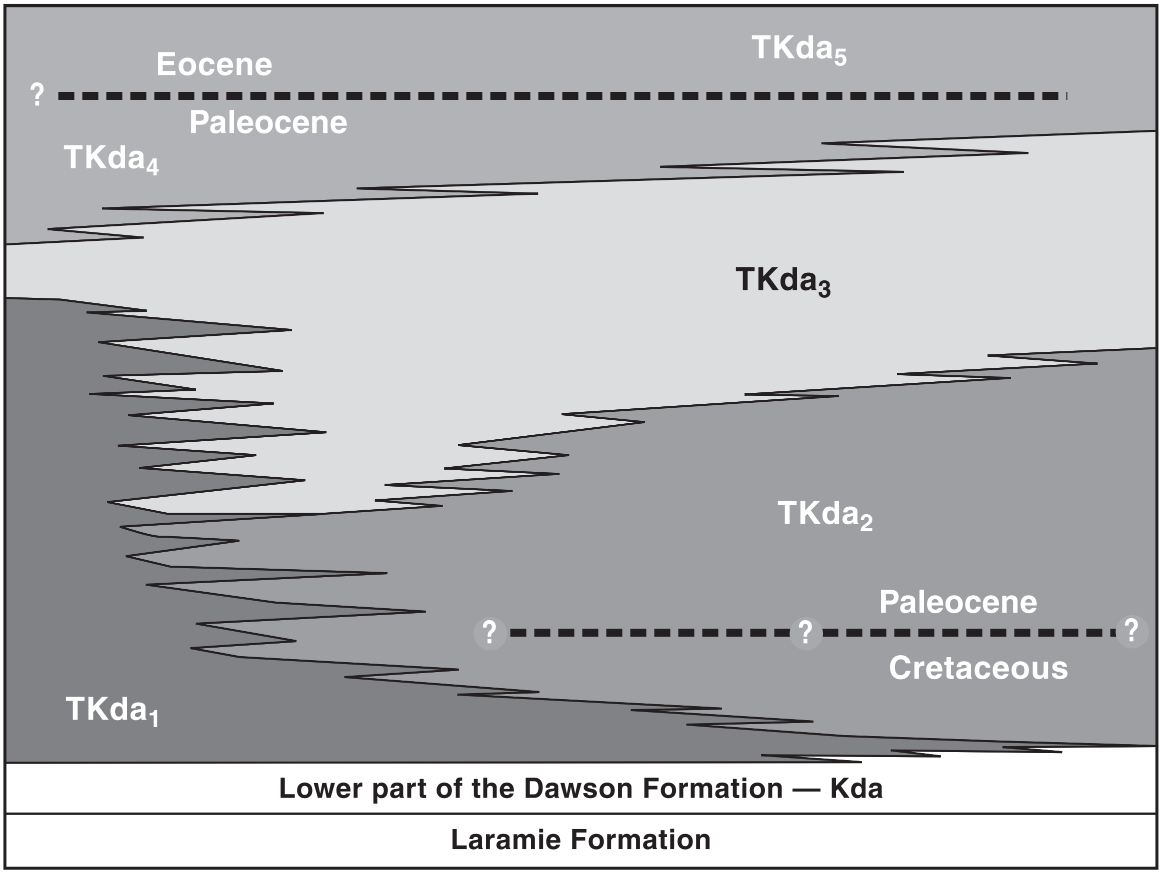

Figure 6. Diagrammatic sketch showing the regional relationships between facies units of the upper part of the Dawson Formation in the Colorado Springs area. The Monument quadrangle is roughly represented by the upper left quarter of the diagram. Heavy dashed lines indicate the approximate stratigraphic locations of geologic time lines. The heavy dashed line in the upper left represents the approximate location of outcrops of the paleosol thought to be the Paleocene–Eocene boundary.

current directions and facies relationships of facies unit two suggest that the source for the sediments of this unit was south and west of the Elsmere quadrangle (Madole and Thorson, 2002). It is likely that the andesitic conglomerates of the Denver Formation, which are in part coarser than those of facies unit two, were transported from a separate source that was far to the north of the source for facies unit two. Crifasi (1992) has analyzed the thickness and sand/shale ratios of the hydrologic aquifers of the Denver Basin and also argues for multiple sediment distribution systems for each of the units.

In defense of the possible extension of the Denver Formation south to Colorado Springs, both Robson (1989, p. 10) and Crifasi (1992, p. 26) have shown that the Denver aquifer contains more shale and less sandstone than the units above and below it. The geologic subdivisions of the upper part of the Dawson Formation used here also follow this general grain-size relationship. Facies units two and three are finer grained and contain more claystone and sandy claystone beds than facies units one and four. Facies units two and three are at least partially derived from an andesitic source area. However, until the subdivisions of the Dawson Formation between the Monument and Kassler quadrangles can be described from lithologic samples from taken from the subsurface, the stratigraphic relations between the Arapahoe, Denver and Dawson Formations of the Denver area and the Dawson Formation of the Colorado Springs area will probably remain unclear.

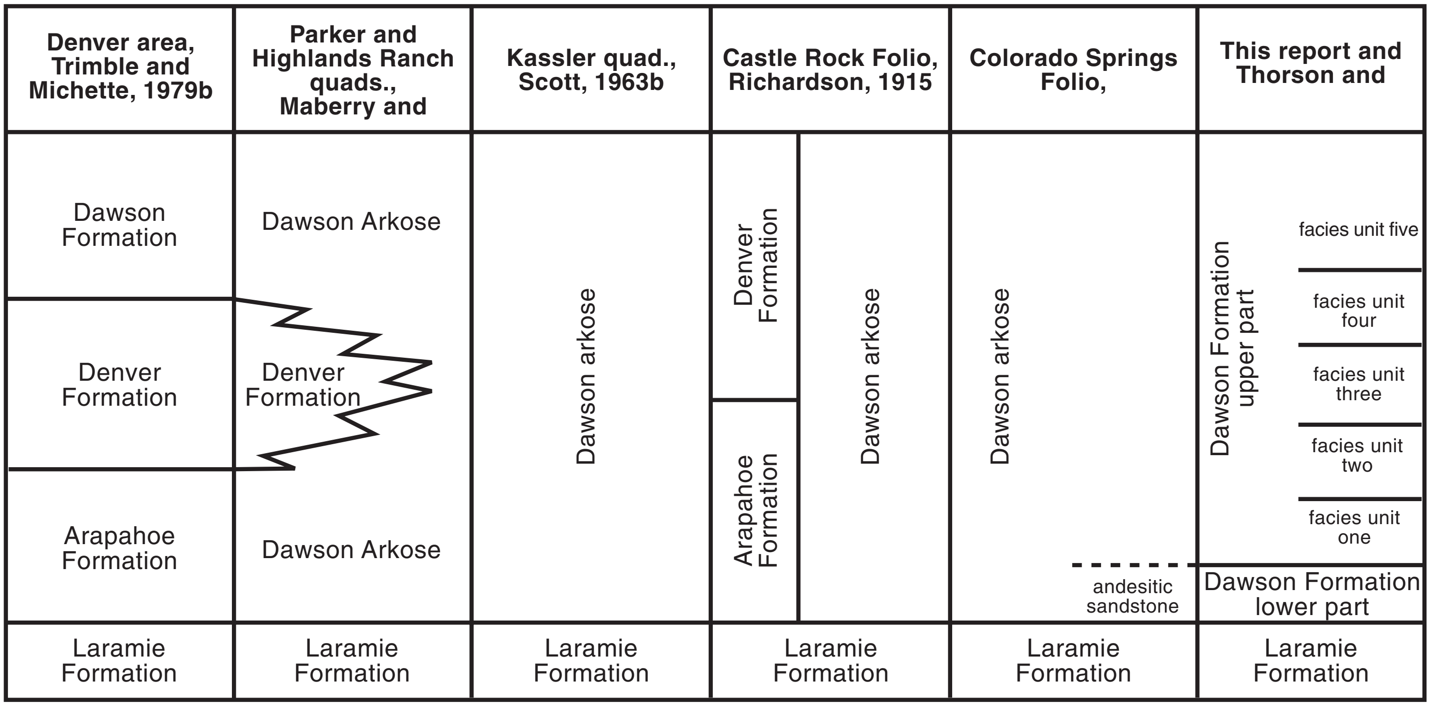

Figure 7. Relationship between the subdivisions of the Dawson Formation used in this report and the stratigraphic nomenclature of the Denver area.

AGE OF THE UPPER DAWSON FORMATION

The upper part of the Dawson Formation spans the Cretaceous–Tertiary (K–T) boundary, but the exact location of the time boundary near the western edge of the basin has not been located. Kluth and Nelson (1988) reconfirmed the Late Cretaceous (late Maastrichian) age for the upper part of the Dawson Formation on the U.S. Air Force Academy. In the Elsmere quadrangle the K–T boundary has been approximately located about 370 ft above the base of the upper part of the Dawson Formation (Benson, 1998; Benson and Johnson, 1998; Johnson and Raynolds, 2001; Madole and Thorson, 2002). The base of the upper part of the Dawson Formation crops out in the Pikeview quadrangle, south of the Monument quadrangle. The sedimentation rate in the Monument quadrangle, which is nearer the mountain-front sediment source, was probably greater than in the Elsmere quadrangle. Therefore, a greater thickness of upper Dawson Formation strata may be present between the base of the upper Dawson Formation and the K–T boundary, but that thickness can not be determined until the K–T boundary is located. The fossil leaf locality known as Scotty's Palm (DMNH-1204, NE$^1/_4$SW$^1/_4$ sec. 12, T. 12 S., R. 67 W.) is Paleocene in age and located about 600 ft above the base of the upper part of the Dawson Formation (Johnson, 2001). Therefore much of the upper part of the Dawson in the Monument quadrangle is suspected to be Paleocene in age. A well-developed paleosol found at several localities in the Monument quadrangle may be a regional paleosol traced around the basin by Soister and Tschudy (1978) and proposed to mark the Paleocene–Eocene boundary. This paleosol has been used as the boundary between facies units four and five in the Monument quadrangle. Thus, facies unit four must be wholly Paleocene and facies unit five is Eocene.

SURFICIAL DEPOSITS

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

af — **Artificial fill (late Holocene)—**Gravel, sand, silt, clay, and rock or concrete debris emplaced for constructing highways, railroads, dams, and commercial and residential structures. Thickness generally is between 5–30 ft.

ALLUVIAL DEPOSITS—Sand, silt, gravel, and clay transported and deposited by flowing water in channels or as unconfined runoff (sheet flow). Deposits resulting from unconfined runoff are referred to as sheetwash alluvium and are distinguished from stream-deposited (fluvial) alluvium, which is the principal deposit underlying flood plains and stream terraces.

Qa — **Channel and flood-plain alluvium (late Holocene)—**Pale-brown to brown sand, gravel, silt, and minor clay underlying narrow flood plains, stream channels, and, locally, low terraces. In most places, the channels and narrow flood plains are incised. In the upper reaches of the larger valleys, channels are cut into bedrock to depths 1–8 ft below the alluvium that blankets valley floors. Unit is generally coarser, lighter in color, and more poorly sorted than unit Qt_1. In many places, the unit is so young that plant roots have scarcely disturbed or destroyed stratification that extends nearly to the ground surface. Typically soil has not developed. Unit is subject to frequent flooding. Estimated thickness is 3–7 ft.

Qt_1 — **Terrace alluvium one (Holocene and late Pleistocene)—**Pale-brown and brown to grayish-brown and dark-grayish-brown beds of sand, silty fine sand, sandy silt, clayey silt, and gravel. Generally, stratification is weakly expressed, and texture and composition vary along the valley axis. The variability is due primarily to differences in sediment input from tributaries that (1) vary in stream power and (2) drain areas underlain by different materials. The unit includes both the Husted Alluvium and Monument Creek Alluvium of Varnes and Scott (1967). Even though these two alluviums are easily distinguished locally, they were included in the same unit because in many places their upper surfaces are at nearly the same level, which makes it difficult to differentiate them where good exposures are lacking. This is especially true in the smaller valleys of the area. The upper surface of the unit is 5–25 ft higher than Monument, Black Squirrel, and Kettle Creeks, but is only about 3–10 ft higher than the smaller streams of the area. Infrequent large floods may inundate Qt_1 in places. Thickness is estimated to be 5–35 ft.

Qt_2 — **Terrace alluvium two (late-middle Pleistocene)—**Very pale-brown to brown, extremely poorly sorted sand and subordinate amounts of gravel. Along Monument Creek, the gravel matrix is chiefly very coarse and coarse sand and the gravel fraction consists primarily of pebbles and small cobbles. In places, the unit also contains large cobbles and small boulders, mostly of Pikes Peak Granite. Along streams draining from the upland east of Monument Creek, the unit consists chiefly of sand and sandy fine pebble gravel (mostly 0.08–0.32 inches in size) that reflect the dominant grain sizes of the Dawson Formation from which they were derived. Exposures of Qt_2 are poor in all drainage basins and are limited to shallow road cuts and a few abandoned gravel pits. The unit corresponds to the Kettle Creek Alluvium of Varnes and Scott (1967). The upper surface of the unit is typically 35–40 ft higher than Monument Creek. Thickness is 5–20 ft.

Qt_3 — **Terrace alluvium three (late-middle Pleistocene)—**Chiefly pale brown to strong brown, extremely poorly sorted sand and gravel that underlie terrace remnants along the larger streams of the area. In the upper reaches of Monument Creek, the unit consists of sand, pebbles, cobbles, and boulders that were derived mainly from granitic rocks of the Rampart Range to the west. Similar large clasts of granitic rock are not present in deposits of Qt_3 in valleys that originate in the Black Forest, which is underlain by the Dawson Formation. The upper surface of the unit is 50–60 ft higher than Monument, Black Squirrel, and Kettle Creeks but is only about 30 ft higher than lesser streams such as Monument Branch. Estimated thickness is 5–30 ft.

Qg_1 — **Older gravel one (late-middle Pleistocene)—**Chiefly brown to reddish-brown, extremely poorly sorted sand and coarse gravel, which includes abundant boulders as well as pebbles and cobbles. Most clasts are Pikes Peak Granite. The unit underlies a surface that parallels Monument Creek on the west and extends up valleys that join Monument Creek from the west. The surface is 80–120 ft higher than Monument Creek. The unit is exposed in a shallow roadcut in the NE1/4 sec. 13, T. 12 S., R. 67 W. Otherwise, little sedimentological information is available for the unit, beyond what can be inferred from landforms and clasts on the ground surface and descriptions provided by Varnes and Scott (1967). The unit includes the type locality of their Pine Valley Gravel. Estimated thickness is 20–40 ft.

Qg_2 **Older gravel two (middle Pleistocene)—**Brown to reddish-brown, extremely poorly sorted sand and coarse gravel, which includes boulder beds as well as pebbles and cobbles. Most clasts are Pikes Peak Granite. The unit caps ridges and knolls in the southwestern part of the quadrangle. Unit composition and texture are inferred from landforms and clasts on the ground surface and descriptions provided by Varnes and Scott (1967), who named the unit Douglass Mesa Gravel. The upper surface of unit Qg_2 is about 100 ft higher than adjacent valley floors and 200 ft higher than Monument Creek. Estimated thickness is 5–50 ft.

Qg_3 **Older gravel three (early? Pleistocene)—**Sediment is similar to unit Qg_2. It also caps ridges and interfluves in the southwestern part of the quadrangle. This unit is the Lehman Ridge Gravel of Varnes and Scott (1967). The upper surface of unit Qg_3 is about 160–220 ft higher than adjacent valley floors and 380 ft higher than Monument Creek. Thickness may exceed 65 ft.

Qau **Alluvium, undivided (Holocene and Pleistocene)—**Chiefly pale-brown to brown, poorly sorted sand and fine gravel in valley heads in the central part of the quadrangle. The unit includes sheetwash and stream-deposited alluvium that are undivided. Reasons for not differentiating these deposits include (1) different ages of alluvium are superposed, (2) exposures are poor, and (3) two or more units are present but are too small to show separately at the map scale. These alluvial-filled valley heads are not exhumed or deeply incised. The unit probably includes sediment that is correlative with units Qsw, Qa, Qt_1, and possibly Qt_2. Estimated thickness is 3–30 ft.

Qps_1 **Younger paleochannel sand (middle-middle Pleistocene)—**Unit is similar in form, origin, and presumably character to unit Qps_2. It comprises three small deposits on the north side of Black Squirrel Creek near the south edge of quadrangle. No sedimentological information is available for these deposits. Unit is about 80 ft higher than Black Squirrel Creek. Qps_1 may be correlative with Qg_1, although there is no reason to assume that all alluvial surfaces and paleochannel deposits have correlatives elsewhere in the area. Some may simply mark the time when part of a drainage system was abandoned because of avulsion (channel abandonment, commonly during floods) or stream piracy. Estimated thickness is 5–25 ft.

Qps_2 **Older paleochannel sand (early-middle Pleistocene)—**Chiefly very pale-brown, conspicuously stratified medium to very coarse sand and thin beds and lenses of fine pebble gravel, most of which is 0.08–0.20 inches in size. Strata are typically 0.2–1.2 in. thick. In addition, gravel exists in lenses that resemble small, shallow channel fills. The lenses observed in several excavations were 1–10 in. thick and 4–10 ft wide. The gravel is well rounded and contains minimal matrix (material smaller than about 0.08 in or 2 mm). These paleochannel deposits are topographically inverted and now cap some of the higher bedrock surfaces in the landscape. Unit Qps_2 is better sorted and stratified than terrace alluvium along Monument Creek. It was derived primarily from arkosic sandstones of the Dawson Formation by streams that were ancestral to the principal streams of today. The deposits are 120–150 ft higher than Black Squirrel Creek and Monument Branch. The unit may be correlative with Qg_2, but likewise, it may not correlate with other units in the area for the reasons discussed above in unit Qps_1. Thickness may exceed 55 ft.

Qsw **Sheetwash (Holocene and late Pleistocene) —** Typically, pale-brown to brown, extremely poorly sorted sand, silty and clayey sand, and minor amounts of gravel. Unit consists chiefly of material transported from the upper parts of valley-side slopes by sheet flow, but also includes some sediment delivered by runoff from rills and minor gullies. Unit Qsw exists principally in sheets and wedges along valley sides and footslopes. Estimated thickness is 3–15 ft.

Qaf **Alluvial-fan deposits (Holocene and late Pleistocene)—**Pale-brown to brown, very poorly sorted sand, silt, and minor gravel deposited by ephemeral tributary streams on fans at the edges of valley floors. Estimated thickness is 5–20 ft.

Qas_1 **Younger piedmont-slope alluvium (Holocene and late Pleistocene)—** Unit is similar in form and origin, and presumably character, to unit Qas_2, but it is poorly exposed and less extensive. Most of the unit consists of thin alluvium on slopes that grade from areas where bedrock is at or close to the surface toward the larger streams of the area. It includes both sheetwash and stream-deposited alluvium that probably are correlative with some of unit Qa, Qt_1, and Qsw along Monument Creek and its tributaries in the southwestern part of the map area. Estimated thickness is 5–15 ft.

Qas_2

Middle piedmont-slope alluvium (middle Pleistocene)—Unit consists of thin beds of very pale-brown to brown, poorly sorted sand and sandy fine pebble gravel (mostly 0.08–0.3 inches in size) that are similar to those of Qps_2. Unit comprises sheetwash and stream-deposited alluvium. Individual channel fills and terrace deposits within this unit were not differentiated because they are products of a complex history that includes random channel avulsion (abandonment) and stream piracy. Collectively, the deposits of Qas_2 span a broad range of time and may be equivalent to several other units in the area (see Figure 4). Some of unit Qas_2 near Monument Creek in the west-central part of the map area (notably sec. 35, T. 11 S., R. 67 W.) is younger than unit Qt_3. Estimated thickness 5–40 ft.

Qas_3

Older piedmont-slope alluvium (early? Pleistocene)—Unit is similar in form, and presumably character and origin, to unit Qas_2. The largest remnant of unit Qas_3 in the quadrangle is at the upper end of the interfluve between Smith Creek and Monument Branch. No sedimentological information is available for the unit. Estimated thickness 5–15 ft.

QTa

Alluvium of Palmer Divide (early? Pleistocene or Pliocene ?)—Unit is variable but composed generally of very pale brown and pinkish brown, fine to coarse sand interbedded with pinkish gray to light brownish gray pebble gravel. The sand is poorly sorted, medium to thin bedded, thinly laminated, and composed largely of quartz grains. The sand beds exhibit bedding and lamination features characteristic of fluvial deposition. The gravel is composed largely of subangular to subround fragments of white or light gray quartz, light pink to light red and reddish brown feldspar, and fragments of pink to light red to reddish brown granite. The gravel occurs in thick massive beds and as thin beds, small lenses, and laminae in clearly fluvial sand. Weathered and deflated surfaces of these deposits are covered with a lag of subround pebbles in which white quartz pebbles stand out prominently.

In the deposit on Palmer Divide (Efi sec. 20, T. 11 S., R .66 W.) sand and gravel of the above character are interbedded with cobble and boulder gravel composed of (1) round to sub-round clasts of pink to reddish brown Pikes Peak Granite, (2) subround buff to light brown clasts of weathered Dawson Formation arkose, (3) subangular to subround clasts of white and light gray quartz, and (4) angular to subangular gray and light brownish gray welded tuff that resembles the latest Eocene Wall Mountain Tuff (McIntosh and Chapin, 1994). Matrix between the cobble and boulder clasts is unstratified gray sand and pebble gravel. In the sand and gravel beds that are interbedded with the cobbles and boulders, bedding is inclined towards the northeast, which suggests northeast-directed paleocurrents. In SE1/4 sec. 6, T. 11 S., R. 66 W. a lag deposit of cobbles and boulders of granite, quartz, welded tuff, and arkose rests on weathered bedrock of the Dawson Formation and is overlain by light brown alluvial sand. The alluvium of Palmer Divide is up to about 60 ft thick.

MASS-WASTING DEPOSITS—Earth materials that were translocated down-slope under the influence of gravity. Mass wasting differs from other modes of material transport in that the material moves as a mass rather than as individual fragments or particles borne along by a transporting medium such as wind or flowing water. Although water is an important constituent of most mass movements and commonly triggers movement, water is part of the moving mass rather than the transporting agent. Although creep (imperceptible, gradual, progressive downslope movement of earth materials) is a form of mass wasting, material transported by creep is not mapped as a separate unit in this study. Creep exists to some degree on most slopes, but it is slow and its contribution to surficial deposits such as colluvium generally cannot be discerned in the field or on aerial photography. Colluvium and debris-flow deposits are the principal products of mass wasting in the Monument quadrangle.

Colluvium, as used here, adheres in most respects to Hilgard's (1892) definition. According to Hilgard, the principal attributes of colluvium are that it (1) was derived locally and transported only short distances, (2) may contain clasts of any size, (3) has no structures indicative of sedimentation or stratification by water flowing in channels, and (4) has an areal distribution that bears no relation to channelized flow of water. Hilgard's definition allows colluvium to include a minor amount of sheetwash alluvium, whereas sheetwash alluvium is excluded in Merrill's (1897) definition of colluvium. Merrill defined colluvium as resulting wholly from "the transporting action of gravity." As used here, colluvium does not include sheetwash alluvium, except for minor amounts or deposits that are too small to map separately.

Qc

Colluvium (Holocene and late Pleistocene)— Unit comprises slope deposits that consist chiefly of very pale-brown to brown sand and fine gravel. Deposits typically are massive and very poorly sorted to extremely poorly sorted. Although primarily the product of mass wasting, the unit may include minor amounts of sheetwash. Colluvium generally accumulates on or near the base of slopes that are steeper than 25 percent (14°). Unit is estimated to be 2–10 ft thick.

Qdf

Debris-flow deposits (Holocene? and Pleistocene)—Extremely poorly sorted matrix-supported gravel in small drainage basins in the southwestern part of the quadrangle. These drainage basins originate in the Rampart Range, which is just west of the map area. No sedimentological information is available for the deposits, other than that inferred from landforms and materials on the ground surface. Clasts are mostly Pikes Peak Granite. These deposits may be of more than one age. Unit postdates unit Qg_1 and could include deposits that are as young as Holocene. Estimated thickness is 5–20 ft.

EOLIAN DEPOSITS—Wind-deposited sediment.

Qes

Eolian sand (middle and early Holocene and late? Pleistocene)—Very pale-brown, pale-brown, and light-yellowish-brown sand. Unit is predominantly very coarse sand and coarse sand that appears to have been deposited as sand sheets. Unit typically has thin, weakly developed soils (4–12 in. thick A horizons and A/AC/C profiles). However, these soils are thicker, have better developed (albeit weakly developed) soil structure, and are more organic-rich than soils in upper Holocene eolian sand elsewhere in eastern Colorado (Madole, 1994, 1995). Soils of the Blakeland series (Larsen, 1981) are developed in unit Qes. Thickness is estimated to be 3–15 ft.

BEDROCK DEPOSITS

Dawson Formation (Upper Cretaceous to Eocene)—The Dawson Formation is divided into upper and lower parts in the Colorado Springs area (Figure 5). The lower part, composed almost exclusively of andesitic debris, is not exposed in the Monument quadrangle. It does occur in the subsurface, and is shown in the cross section on the accompanying plate. The lower part of the Dawson Formation is entirely Upper Cretaceous in age. The upper part of the Dawson Formation is a mixture of andesitic and arkosic material deposited during the Late Cretaceous and early Tertiary. The upper part of the Dawson Formation is divided into facies unit one ($TKda_1$), facies unit two ($TKda_2$), facies unit three ($TKda_3$), facies unit four ($TKda_4$), and facies unit five ($TKda_5$). These facies units are differentiated on the relative proportions of andesitic and arkosic material, on the thickness and style of coarse-grained bedding units, and on the relative proportion of fine-grained claystone and siltstone versus coarser-grained beds of sandstone, arkose, pebbly arkose, and pebble conglomerate.

$TKda_1$

Facies unit one (Upper Cretaceous to Paleocene)—This facies unit is composed of white to light gray, cross-bedded or massive, very coarse arkosic sandstone, pebbly arkose, or arkosic pebble conglomerate. The facies unit contains occasional interbeds of thin- to very thin-bedded gray claystone and sandy claystone, or dark brown to brownish gray, organic-rich siltstone to coarse sandstone containing abundant plant fragments. Facies unit one comprises a coarse "mountain front" synorogenic deposit of sediments that were eroded from a rapidly uplifting Front Range, transported across an active fault zone along the mountain front, and deposited in the western part of subsiding Denver Basin (Figure 6). In the Monument quadrangle facies unit one is at least 700 ft thick in a water well in SW/SW/ sec. 1, T. 12 S., R. 67 W. (Air Academy 2, Varnes and Scott, 1967, Plate 8). The regional geometry of facies unit one suggests that it should thicken to the south and west from this well, towards the mountain front, where it might be at least 900 ft in thickness.

Facies unit one is well exposed along Monument Creek, south of North Gate Boulevard on the U.S. Air Force Academy. Here, six different lithologies are present:

1. Beds of white to light gray very coarse arkosic sandstone, pebbly arkosic sand stone, or arkosic pebble conglomerate dominate the facies. Many outcrops have only beds of this character. These beds are generally very thick, often 8–10 ft, and commonly have steeply inclined cross-bedding and scoured bases. The sand- and gravel-size material in facies unit one is subangular to subround and poorly sorted. The coarse beds have irregularly distributed areas of finer-grained and better-sorted, more quartz-rich, sand stone that is composed mostly of gray and clear fine- to medium-grained quartz. Clasts of this finer, more quart zose but still arkosic, sandstone occur as ripped-up and included sandstone clasts in the pebble conglomerate beds.

   Rip-up clasts of finer-grained gray clay stone are also common in the coarse arkose beds. The character of the sediments and sedimentary structures of the upper Dawson Formation conglomerate beds suggest deposition in energetic fluvial environments, probably braided streams. The pebbles in these coarse-grained beds are dominated by subround fragments of quartz up to 3 in. in diameter. Also common as clasts are pieces of recognizable white or light gray granite and fragments of white feldspar, up to 1.5 in. in size. The granite and feldspar clasts commonly have perthitic or "graphic granite" textures. Minor amounts of pebbles composed of chert, smoky quartz, or metamorphic rocks occur locally. Pebbles of volcanic origin are extremely rare; their scarcity is significant considering the dominance of andesitic volcanic material in the underlying lower part of the Dawson Formation (Kda member, Thorson and others, 2001).

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

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

4. Interbedded with the gravelly conglomeratic beds are occasional dark brown to brownish gray organic-rich beds of silt- stone to coarse sandstone with abundant plant fragments. These beds are usually structureless and commonly darkest colored at their tops. They may grade downward into coarse pebbly arkose or mudflow beds, but the tops are generally sharp and may have load deformation structures where overlain by thick arkosic conglomerate or mudflow beds. These dark beds and the dark zones at the tops of other thick beds, are interpreted as the deposits of ephemeral swamps or swampy soil horizons.

5. In many outcrops of facies unit one occasional beds of thin- to very thin-bedded, light to dark gray claystone, sandy claystone, and fine sandstone are interbedded between thicker beds of arkosic pebble conglomerate and arkosic sandstone. These beds occasionally contain well preserved leaf fossils.

6. Facies one also contains numerous interbeds of 1–3 ft thick, pink, yellow brown, and red paleosols. Numerous

examples can be seen along the banks of Monument Creek, south of North Gate Boulevard on the U.S. Air Force Academy. Greenish gray gritty claystones interbedded with thin lenses of arkosic sandstone are oxidized to red and yellow brown colors in the paleosols. The oxidized claystones contain small fragments of dark brown plant remains and root casts.

Along Monument Creek in the vicinity of the North Gate Boulevard bridge (NW1/4 sec. 12, T. 12 S., R. 67 W.) and northward, strata of facies unit one are interbedded with those of facies unit three. Two important Paleocene leaf fossil sites have been identified in this interbedded sequence by the Denver Museum of Nature and Science. The Scotty's Palm site (DMNH-1204, center sec. 12, T. 12 S., R. 67 W.; Reynolds and others, 2001) has a diverse population of large angiosperm leaves which suggest a tropical rainforest environment of early Paleocene age. The Baptist Road site (DMNH-2177, south edge sec. 26, T. 11 S., R. 67 W.; Johnson and Raynolds, 1998; Reynolds and others, 2001) represents a slightly younger flora which is lower in diversity, has smaller leaves, and contains mixed angiosperm and distinctive coniferous foliage.

Facies unit one is generally permeable, well drained, and has good foundation characteristics. Excavation may be diffi- cult, even though on the weathered surfaces the arkoses are friable and easily eroded. The massive mudflow beds may be hard and tough and may require considerable effort to excavate. The finer-grained interbeds may be less stable and may have greater shrink- swell properties than the arkoses. The block-failure of cliffs in facies one poses a significant slope stability hazard in some areas. Facies one may be equiva- lent to the upper part of Arapahoe Formation and/or Arapahoe aquifer in the Denver area (J. Himmelreich, Jr., 2001, oral commun.).

$TKda_2$ **Facies unit two (Upper Cretaceous to Paleocene)—**Facies unit two does not outcrop in the Monument quadrangle but we infer from regional facies relationships that it is present in the subsurface. Facies unit two is 400–500 ft thick in the Pikeview quadrangle and occurs in the basinward part of that quadrangle (Figure 6). There, unit $TKda_2$ is composed of light gray to greenish gray arkosic sandstone and olive green to brownish-gray, pebbly, andesitic sandstone interbedded with dark gray to grayish green, fine-grained micaceous sandstone and sandy claystone. Facies unit two thickens toward the southeast and is greater than 1,000 ft thick in the Elsmere quadrangle (Madole and Thorson, 2002). Facies two may be equivalent to the Denver Formation and/or Denver aquifer in the Denver area (J. Himmelreich, Jr., 2001, oral commun.).

$TKda_3$ **Facies unit three (Paleocene)—**This facies unit consists of sub-equal amounts of three lithologies: (1) thick and very thick-bedded, massive and cross-bedded, white, tan, and light gray arkose and pebbly arkose; (2) thin to thick beds of light green to olive gray, clay-rich, fine- to medium-grained micaceous and feldspathic sandstone; and (3) thin to thick beds of dark gray to greenish gray sandy claystone. In the southeastern part of the Monument quadrangle the unit is 500–600 ft thick. It thins towards the northwest as it inter-fingers with facies unit one and facies unit four. Along Monument Creek, from downstream of North Gate Boulevard to above Baptist Road, strata of facies unit three interfinger with thick arkosic beds of facies unit one.

The very thick-bedded, massive or cross-bedded, light colored arkose beds in facies unit three resemble those in facies unit one but are finer grained and generally thinner. Most of the grains in these arkoses are less than 0.5 inches in diameter; a few pebbles are up to 1.5 in. The lithologies of the coarse grains are much more varied than those in the arkoses of facies unit one, with grains of quartz, white feldspar, pink feldspar, white granite, pink granite, and small amounts of tan vuggy dolomite and red, black, or orange brown chert. A few subround to round pebbles of altered volcanic rocks occur, but these are the least common of all the clast lithologies.

The light green to olive gray, clay-rich, fine- to medium-grained micaceous and feldspathic sandstone and the dark gray to greenish gray sandy claystone resemble lithologies in the lower part of facies unit two in the Pikeview and Elsmere quadrangles (Thorson and others, 2001; Madole and Thorson, 2002). The finer-grained lithologies in unit $TKda_3$ are characterized by greenish colors, suggestive that the facies contains considerable montmorillonitic clay

(Varnes and Scott, 1967). In exposures of facies unit three in the bed of Monument Creek downstream from Baptist Road (sec. 35, T. 12 S., R. 67 W.) the finer-grained beds of this facies also contain thin, poorly developed paleosols. Facies three ($TKda_3$) is well exposed in the bed and banks of Black Squirrel Creek and Kettle Creek in the southeastern corner of the quadrangle. The Hopi Oil well (NW1/4SW1/4 sec. 31 T. 11 S., R. 66 W.) encountered coaly intervals in strata that have been assigned to facies three, although the coaly beds do not crop out at the surface.

The sandstones and arkoses of facies three are generally stable and have good foundation characteristics. The finer-grained, more clay-rich, lithologies should be expected to be less stable and may have high shrink-swell potential. Facies unit three may be equivalent to part of the Dawson Arkose and/or Dawson aquifer as used in the Denver area (John Himmelreich, Jr., 2001, oral commun.).

Facies unit four (Paleocene)—This facies unit of the upper part of the Dawson Formation is similar to facies unit one ($TKda_1$). The $TKda_4$ unit is dominated by very thick bedded to massive, cross-bedded, light colored arkoses, pebbly arkoses, and arkosic pebble conglomerate. Facies unit four contains numerous beds of white to light tan, fine- to medium-grained feldspathic cross-bedded friable sandstone. These sandstones are poorly sorted, have high clay contents, and are often thin or medium bedded; wavy bedding and ripple cross-laminations are common. Unit $TKda_4$ contains massive structureless beds which interpreted as mudflows; these beds occasionally have dark colored tops that are organic-rich soil zones. Facies four contains only rare interbeds of thin- to very thin-bedded gray claystone and sandy claystone, or dark brown to brownish gray, organic-rich siltstone to coarse sandstone containing plant fragments. Facies four is about 500 ft thick in the part of the quadrangle shown on the cross section; its map distribution suggests that it may thin to the northwest and thicken to the southeast from there.

The top of facies unit four is a strongly developed paleosol that was traced around the Denver Basin by Soister and Tschudy (1978). This paleosol is a recessive unit and may not be continuous, but several man-made exposures allow it to be followed across the quadrangle. Near the town of Monument a stratigraphic interval containing multiple of paleosols is exposed in road cuts and roadside ditches on Beacon Lite Road in the NE1/4SE1/4 sec. 10, T. 11 S., R. 67 W. Here bright maroon to dark red, very clayey, coarse sandstone and fine-pebble conglomerate are interbedded with very coarse light gray to pink pebbly arkose and pebble conglomerate in a sequence of strata about 40 ft thick. The reddish colored zones are often mottled with yellow brown and greenish gray patches, and are cut by root structures. These reddish colored zones are very clayey and have very coarse sand- size grains or fine pebbles of clear and light to dark gray quartz in a matrix of red, maroon, yellow brown, or greenish gray sandy claystone. The quartz grains are generally matrix supported. In facies unit four, beds with very coarse sand-size grains and small pebbles are usually arkosic, contain abundant feldspar, and are grain supported. The reddish colored strong paleosol zones are interpreted to be arkoses in which the feldspars have been altered to clay during protracted periods of weathering and oxidation leaving only the resistant quartz grains in a red clay matrix. This paleosol horizon can be followed intermittently west from the Beacon Lite Road exposure into the Palmer Lake quadrangle. Another exposure of paleosol, which is correlated with the paleosol exposed along Beacon Lite Road, is exposed on the east shore of Lake Woodmoor (NW1/4NE1/4 sec. 14, T. 11 S., R. 67 W.). A third exposure of a paleosol correlated with the Beacon Lite paleosol crops out at the corner of Lake Woodmoor Drive and Highway 105 (C sec. 13, T. 11 S., R. 67 W.).

A similar paleosol was exposed in the excavation for a residence at the corner of Brenthaven Court and Colonial Park Drive (just off Higby Road, SW1/4NW1/4 sec. 20, T. 11 S., R. 66 W.) early in June, 2001. At that time, about 10 ft of mottled red orange and olive green to yellow green clay-rich arkose and sandy claystone was exposed. This paleosol contained well preserved root structures and a filled burrow about 1 inch in diameter. Part of this paleosol is still exposed in the roadside ditch along Brenthaven Court. Another exposure of the Brenthaven horizon occurs in the roadside ditch along Dolan Drive about 2,000 ft to the southeast.

Another well-developed paleosol exposure, about 30 ft thick, is exposed in a road cut on Highway 83 about 300 ft south of Stage Coach Road (SW1/4NE1/4 sec. 34, T. 11 S., R. 67 W.). Several additional partial exposures of the same paleosol horizon are exposed between the Highway 83 and the Brenthaven localities. The locations of exposures of these paleosols are shown on the map, along with dashed lines of its proposed projections. This paleosol is part of an extensive regional paleosol that marks the Paleocene/Eocene boundary, and the boundary between the D1 and D2 subdivisions of the Dawson Formation proposed by Raynolds (1997, 2001a, 2001b; Farnham, 2001a, 2001b).

Facies unit four is generally permeable, well drained, and has good foundation characteristics. Excavation may be difficult, even though the arkoses are friable and easily eroded on weathered outcrops. The massive mudflow beds may be hard and tough and may be well indurated and require considerable effort to excavate. Rock fall from cliffs in facies unit four poses a significant slope stability hazard in some areas. Facies unit four may be equivalent to the Dawson Arkose and/or Dawson aquifer in the Denver area (George Vanslyke, 2001, oral commun.).

$TKda_5$ **Facies unit five (early to middle(?) Eocene)—** This facies unit of the upper part of the Dawson Formation is similar to facies units one and four. It was mapped as a separate unit because it follows the prolonged episode of weathering and oxidation that resulted in the paleosol at the top of facies unit four. Facies unit five was deposited by energetic streams that carried coarse-grained arkosic sediments into the basin when uplift of the Front Range resumed.

The $TKda_5$ unit is dominated by very thick bedded to massive, cross-bedded, light colored arkoses, pebbly arkoses, and arkosic pebble conglomerate, but the individual grains of feldspar or granite are often pink instead of light gray to white as in units $TKda_1$ and $TKda_4$. Facies unit five contains common beds of white to light tan, fine- to medium-grained feldspathic, cross-bedded friable sandstone. These sandstones are poorly sorted, have high clay contents, and are often thin or medium bedded; wavy bedding and ripple cross-laminations are common. Facies unit five also contains massive structureless beds interpreted to be the mudflows. Facies five is about 500 ft thick in the northeast part of the quadrangle; the top of the unit has been removed by erosion.

In the northwestern part of the quadrangle facies unit five contains thin, poorly developed, red, pink, and yellow brown paleosol oxidized zones interbedded with, or developed within, the thick arkoses. A good example of these poorly developed paleosols is exposed along the driveway to Colorado Engineering and Geotechnical Group at 19375 Beacon Lite Road, north of the town of Monument, Colorado (NW1/4 sec. 11, T. 11 S., R. 67 W.).

Facies unit five is generally permeable, well drained, and has good foundation characteristics. Excavation may be difficult, even though the arkoses are friable and easily eroded on weathered outcrops. The massive mudflow beds may be well indurated and may require considerable effort to excavate. Facies unit five appears to be equivalent to the Dawson Arkose and/or Dawson aquifer in the Denver area (George Vanslyke, 2001, oral commun.).

Kda **Lower part of Dawson Formation (Upper Cretaceous)—**Yellowish green and greenish gray to olive brown sandstone interbedded with grayish green to dark green and brown to brownish gray siltstone and sandy claystone; composed almost exclusively of andesitic debris. About 300 ft thick; shown only on the cross section that accompanies the geologic map.

Kl **Laramie Formation (Upper Cretaceous)—** Yellowish gray, olive gray and brownish gray sandy shale and thick- to very thick-bedded, white, light gray, or light orange sandstone. About 600 ft thick; shown only on the cross section that accompanies the geologic map.

Kf **Fox Hills Sandstone (Upper Cretaceous)—** Greenish gray to yellowish brown micaceous sandstone. About 150 ft thick; shown only on the cross section that accompanies the geologic map.

Kp **Pierre Shale (Upper Cretaceous)—**Dominantly gray to dark gray shale. About 4,500 ft thick; upper part shown on the cross section that accompanies the geologic map.

Table 2. Active permits for sand and gravel operations in the Monument quadrangle.

Company	Operation	Permit No.	Location	Commodity
Colorado Silica Sand, Inc.	Northgate No. 1	M-1998-006	sec. 16, T. 12 S., R. 66 W.	sand
Colorado Silica Sand, Inc.	Middle Creek Manor Backslope	M-1999-052	NW⁄ NW⁄ sec. 8, T. 12 S., R. 66 W.	sand
Oglebay Norton Industrial Sands, Inc.	Erin Pit	M-1991-041	SW⁄ NW⁄ sec. 16, T. 12 S., R. 66 W.	sand
Raymond F. and Robert W. Dellacroce	Dellacroce Pit	M-1993-050	NW⁄ sec. 34, T. 12 S., R. 67 W.	sand

STRUCTURAL GEOLOGY

The structural geology of the Monument quadrangle is not complex. Bedrock units dip gently to the northeast at 3°–5° across most of the quadrangle. Strike and dip symbols are not abundant on the map because of the poor outcrop exposures; those symbols shown are mostly measured from man-made exposures or cut-banks along stream drainages. Measurement of strike and dip in the Dawson Formation is a difficult and questionable because of the coarse-grained, lenticular and cross-bedded character of most of the beds. Bedding surfaces and cross-bed orientation from these beds were inclined at deposition, and are unlikely to be representative of the strike and dip of the whole unit. Strike and dip measurements shown on the map were made on thin-bedded, fine-grained strata which were deposited in a horizontal orientation.

A small anticline appears on the cross-section and is shown with querries on the map. This structure is interpreted from logs of wells shown on the cross section, in which the Lower Dawson Formation (Kda) and Laramie Formation (Kl) have distinctive characters. The orientation of the axis of this structure on the map is questionable but is consistent with regional structure. The reversal of dip in this structure is not visible at the surface.

MINERAL RESOURCES

Sand and gravel are the most significant mineral resources in the Monument quadrangle. Thin coal beds occur in facies three of the upper part of the Dawson Formation, but there is no recorded mining of these beds in the Monument quadrangle. Test wells for oil and gas reported no shows and were abandoned. No metallic or radioactive mineral resources are known in quadrangle. Clay has been mined from pits in the Monument quadrangle, but none are currently active or permitted.

SAND AND GRAVEL

Although many permit applications for sand and gravel operations in the Monument quadrangle have been filed with the Colorado Department of Natural Resources, Division of Mines and Geology, only four are still active (Table 2). Sand and gravel are widely available from surficial deposits derived by erosion of the Dawson Formation, as at the Colorado Silica Sand and Oglebay Norton pits. The Dellacroce Pit is producing sand and gravel from an alluvial deposit composed of material largely eroded from the Pikes Peak Granite west of the Monument quadrangle.

COAL

In the early to middle 1900s, coal mining from seams in the Laramie Formation was a major industry in the Colorado Springs area. These coal-bearing beds are probably present beneath the Monument quadrangle at depths of about 1,000–1,500 ft but they were not mined this far down-dip from their outcrops in the Pikeview, Colorado Springs, and Elsmere quadrangles (Del Rio, 1960).

OIL AND GAS

The Colorado Oil and Gas Commission has completion cards for three petroleum test wells drilled in the Monument quadrangle. In 1958 Hopi Oil drilled the No. 1 Hans Saue well (NE1/4NE1/4 sec. 31, T. 11 S., R. 66 W.) to a depth of 1,665 ft. A driller's sample log from this well is available at the Oil and Gas Commission. Interpretation of an electric log (SP and Resistance) for this well, found in the well files of the Colorado Division of Water Resources, indicates that this well was drilled into the upper part of the Cretaceous Laramie Formation.

In 1968 George Schoonmaker drilled the No. 1 and No. 1-X Rainbow Valley wells in NE1/4NE1/4 sec. 17, T. 12 S., R. 66 W. The No. 1 Rainbow Valley was drilled to 675 ft and abandoned. The No. 1-X Rainbow Valley was drilled from a location about 50 ft away and drilled to 2,400 ft. The well completion card indicates that the No. 1-X Rainbow Valley encountered the Laramie Formation at 1,360 ft and the Fox Hills Sandstone at 1,820 ft. No electric logs from this well were found. None of the wells in the Monument quadrangle reported any shows of oil or natural gas and were abandoned. The nearest oil production is 30 mi. southwest of Colorado Springs in the Canon City Basin, where oil is produced from a fractured Pierre Shale reservoir in the Florence oil field.

URANIUM

No occurrences of radioactive minerals have been reported from the Monument quadrangle, although a small uranium prospect is located in the northwest corner of the Pikeview quadrangle (Burgess claim, NE1/4 sec. 22, T. 12 S., R. 66 W.; Thorson and others, 2001; Nelson-Moore and others, 1978). This prospect, about 0.25 mi. from the south edge of the Monument quadrangle, occurs in limonite-cemented arkoses of facies unit three of the upper part of the Dawson Formation. Gamma-ray logs from water wells in facies units three and four of the upper Dawson in the Monument quadrangle occasionally have elevated responses (2–4 times background) which may indicate small low-grade uranium occurrences. Small uranium occurrences in the Dawson Formation have been extensively studied as a geological hazard in the northeastern part of the Colorado Springs metropolitan area (John Himmelreich, Jr., written commun., 2002).

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