OPEN-FILE REPORT 02-2

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

By Richard F. Madole and Jon P. Thorson

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DEPARTMENT OF NATURAL RESOURCES

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FOREWORD

The Colorado Department of Natural Resources is pleased to present the Colorado Geological Survey Open File Report 02-2, *Geologic Map of the Elsmere Quadrangle, El Paso County, Colorado.* Its purpose is to describe the geologic setting and mineral resource potential of this 7.5-minute quadrangle located along the east edge of the Colorado Springs metropolitan area. Richard Madole and Jon Thorson completed the field work on this project in the summer of 2000.

This mapping project was funded jointly by the U.S. Geological Survey (USGS) and the Colorado Geological Survey (CGS). USGS funds are competively awarded through the STATEMAP component of the National Cooperative Geologic Mapping Program (Agreement No. 00HQAG0119). The program is authorized by the National Mapping Act of 1997. The CGS matching funds come from the Severance Tax Operational Account that is funded by taxes paid on the production of natural gas, oil, coal, and metals.

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Robert M. Kirkham (Colorado Geological Survey); John W. Himmelreich, Jr. (Engineering Geologist, Colorado Springs, Colorado); Kirk R. Johnson (Curator of Paleontology, Denver Museum of Nature and Science); and Robert G. Raynolds (Denver Basin Project, Denver Museum of Nature and Science) provided technical reviews that improved this publication. George D. Vanslyke (Colorado Division of Water Resources) provided generous access to his department's files of water-well logs.

The authors thank David S. Fullerton, U.S. Geological Survey, for helpful discussions about the informal time terms used for the Pleistocene. However, the authors are solely responsible for any errors that may be present in the mapping or description of map units. James A. Messerich set photogrammetric models on the Kern PG-2 plotter that was used to make part of this map. Jane Ciener served as the technical editor for this map. The authors thank the many landowners who gave permission to enter their property.

INTRODUCTION

The Elsmere 7.5-minute quadrangle is at the east edge of the Colorado Springs metropolitan area, which is in the southern part of the Colorado Piedmont section of the Great Plains (Fig. 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 and by having a surface that, along its boundaries, is topographically lower than the adjoining physiographic regions (Fenneman, 1931). Older Cenozoic rocks also have been eroded from the Colorado Piedmont, except on the higher, western part of the interfluve between the South Platte and Arkansas rivers. The Elsmere quadrangle is on the south flank of the high part of this interfluve. Consequently, the northern part of the quadrangle includes a thick section of Paleocene rocks, whereas the southern part of the quadrangle is more like the majority of the Colorado Piedmont, a region of low hills and plains underlain by Upper Cretaceous sedimentary rocks.

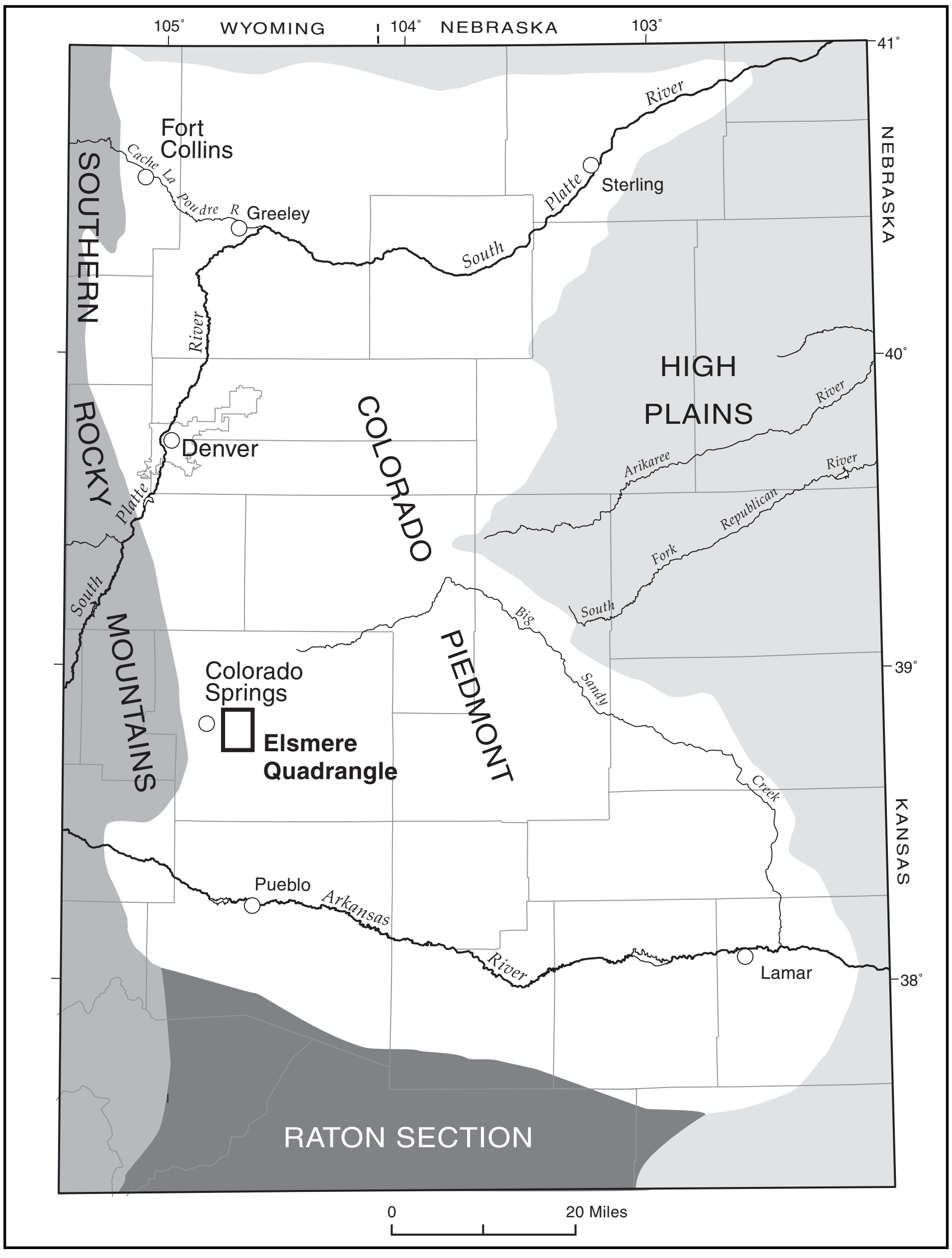


Figure 1. Map showing the location of the Elsmere quadrangle with respect to the Southern Rocky Mountains and the Colorado Piedmont, High Plains, and Raton sections of the Great Plains defined by Fenneman (1931).

Although the western part of the Elsmere quadrangle is heavily urbanized, most of the eastern part is sparsely populated and used primarily for grazing. Urbanization no doubt will continue to expand eastward. Thus, the Elsmere quadrangle was selected for mapping under the STATEMAP component of the National Cooperative Geologic Mapping Act. STATEMAP is intended to produce geologic maps that are useful for a variety of purposes including land-use planning, geotechnical engineering, identifying geologic hazards, and developing or protecting ground water and mineral resources.

Most of this booklet is devoted to an expanded description of the units shown on the geologic map of the Elsmere quadrangle and to discussions of related topics. Responsibility for mapping surficial geology and bedrock geology and authorship of those parts of this booklet that deal with these subjects was divided between the two authors. Madole mapped and described the surficial geology and Thorson did the same for the bedrock geology.

PREVIOUS GEOLOGICAL MAPPING

A large-scale (1:24,000 or larger) geologic map has not been made previously of the Elsmere quadrangle. However, both the Colorado Geological Survey and U.S. Geological Survey have mapped adjacent 1:24,000-scale quadrangles (Fig. 2), and Finlay (1916), Scott and Wobus (1973), and Trimble and Machette (1979a) made small-scale geologic maps (1:125,000, 1:62,000, and 1:100,000, respectively) of large areas that include the Elsmere quadrangle.

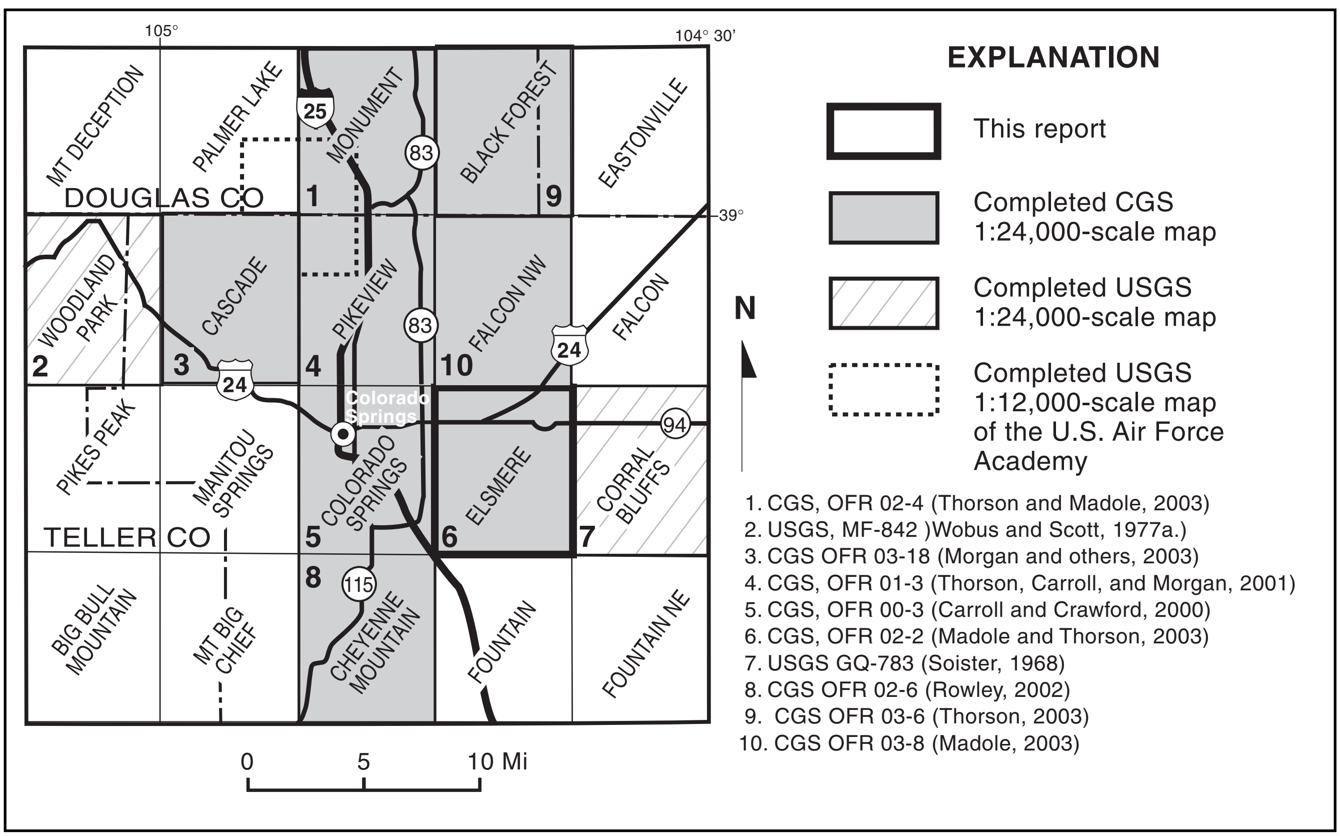


Figure 2. Index to 1:24,000-scale geologic maps in the vicinity of the Elsmere quadrangle. Adapted from Carroll and Crawford (2000).

SURFICIAL GEOLOGY
By R.F. Madole

SETTING

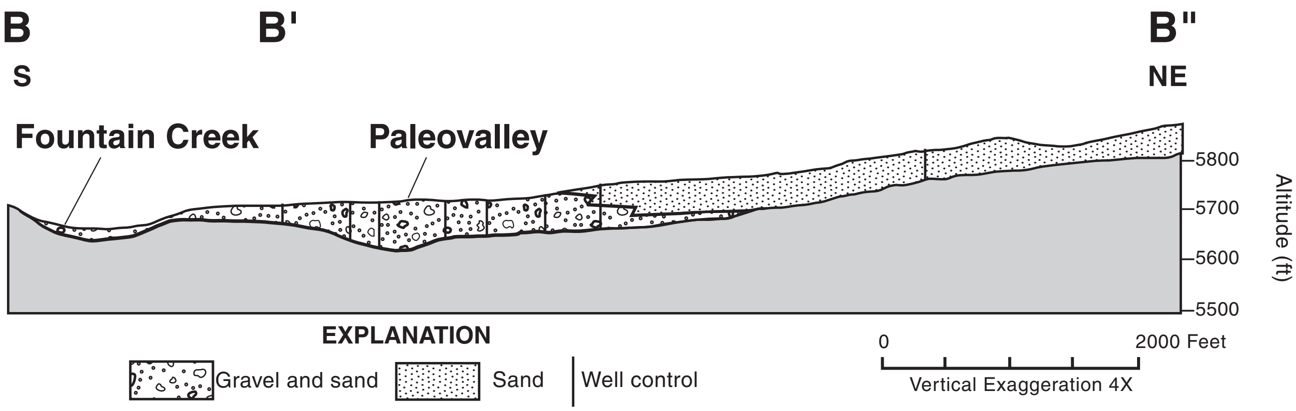
Surficial deposits of alluvial and eolian origin blanket about 70 percent of the Elsmere quadrangle. The quadrangle encompasses two drainage basins, Sand Creek in the northwest and Jimmy Camp Creek in the east, and a broad interfluve between the two basins. Each drainage basin has two main streams and several minor tributaries, all of which are dry most of the year. In both drainage basins, the main streams originate in uplands underlain by the Dawson Formation and flow southwestward to Fountain Creek, which is just beyond the southwest corner of the quadrangle. Even though only a small part of each drainage basin is underlain by the Dawson Formation, alluvial sand from this source is the dominant surficial material in the quadrangle. It is widespread on interfluves and valley floors. Sand Creek is aptly named, and this name would apply equally well to all the main streams of the area. The windblown sand that mantles much of the landscape was derived chiefly from the large volume of alluvial sand present on the floors of the main valleys. Sandy alluvium containing scattered clasts and fragments of petrified wood derived from the Dawson Formation mantles the Pierre Shale over large areas on the upland between Sand Creek and Jimmy Camp Creek in the southern two-thirds of the map area.

Several ages of Quaternary alluvium are present in the quadrangle, but differentiating them is difficult because: (1) eolian sand conceals them over much of the area; and (2) stream systems aggraded during much of the latter part of the Quaternary and, thus, young alluvium buries older alluvium over large areas. On some valley floors, Holocene alluvium is inset in upper Pleistocene alluvium and the upper surfaces of the two units are at the same level. The units are distinguishable only because of pronounced differences in degree of soil development. Water well logs indicate that as much as 80 ft of alluvium underlies the valley floor of Jimmy Camp Creek. Well logs also reveal that a similar thickness of alluvium fills an abandoned paleovalley that is east of and parallel to Fountain Creek, south of the map area (Jenkins, 1964). Sometime during the middle Pleistocene, the streams of the region cut to greater depths than their modern counterparts and then aggraded (Fig. 3). Terrace deposits of late middle Pleistocene age, although conspicuous in most parts of Colorado, are inconspicuous in the Elsmere quadrangle. Possibly, alluvium of this age is the principal deposit beneath the Holocene cover in the Jimmy Camp Creek drainage basin and in the abandoned paleovalleys of the area.

An abandoned paleovalley, now largely concealed by eolian sand, probably passes from northeast to southwest, beneath parts of Peterson Air Force Base and the Colorado Springs Municipal Airport. The deep open pits in sand just beyond the west edge of the quadrangle (secs. 2 and 3, T. 15 S., R. 66 W.) appear to be in this paleovalley. Also, the buried channel referred to as the Widefield aquifer (Radell and others, 1994) may be part of this drainage system. The paleovalley parallels the trends of Sand Creek, East Fork Sand Creek, and upper Jimmy Camp Creek. The valley probably was abandoned when a southward-flowing stream that occupied a more deeply excavated basin on the Pierre Shale captured the upper part of Jimmy Camp Creek. Stream piracy such as this is common in piedmont regions and is the result of differences in flow regimes, load characteristics, and gradients between stream channels draining from uplands and those originating on lowlands (Ritter, 1987).

DELINEATION OF UNITS

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 Elsmere quadrangle partly from photogrammetric models of annotated aerial photographs using a Kern PG-2 plotter and partly by tracing contacts from copies of aerial photographs that were enlarged or reduced to match the map scale. Interpretations based on stereoscopic examination of aerial photographs were verified in places on the ground and were supplemented with data collected along traverses and from fieldwork in selected areas.



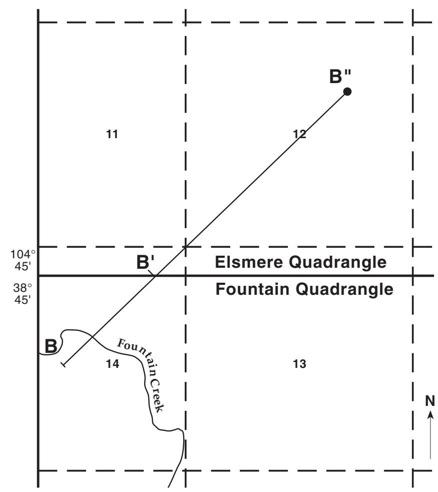


Figure 3. Northeast–southwest cross section across Fountain Creek from locality B" in southwestern Elsmere quadrangle to a locality in northwestern Fountain quadrangle (modified from Jenkins, 1964, section B–B'). This section and two others in Jenkins (1964) show that an ancestral channel of Fountain Creek parallels the course of the present creek and is incised to depths at least 25 ft lower than the bedrock surface beneath the present stream.

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 about 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 five different generations of aerial photography (Table 1). Photography of projects done in 1969 and 1992 was relied on the most in mapping the Elsmere quadrangle. The cultural features of the topographic base map were revised in 1994. Thus, roads, reservoirs, and buildings that were constructed after 1994 are not on the map base, and human-made deposits that postdate the 1992 aerial photography may not be on the map.

The names of all surficial units are informal. Surficial deposits are grouped according to genesis, but the common practice of naming units after the landform with which they are associated or the material of which they are composed is not useful in the Elsmere quadrangle. Few surficial deposits

Table 1. Aerial photography used in mapping the Elsmere quadrangle.

Year	Source[1]	Scale	Project Code	Film Type
July 1947	USGS	1:23,600	GS–ET	B & W
October 1953	USA	1:53,000	001	B & W
October 1969	USGS	1:28,000	GS–VCHS	B & W
August 1988	USGS	1:40,000	NAPP	Color IR
April 1992	RMAS	1:24,000	RMA-8240	B & W

USGS: U.S. Geological Survey; USA: U.S. Army; RMAS: Rocky Mountains Aerial Surveys, Inc.

in the map area are uniquely associated with a single landform, such as a terrace or flood plain, and the physical character of the sediment in many deposits is similar. The surficial units are allostratigraphic rather than lithostratigraphic, which is to say, they are mappable stratiform bodies that are defined and identified on the basis of their bounding unconformities rather than their lithic characteristics and stratigraphic position (North American Commission on Stratigrahic Nomenclature, 1983). Because the surficial units do not conform to the Law of Superposition, time terms, such as early and late, are used for them in the description of map units rather than position terms, such as lower and upper.

MATERIAL PROPERTIES AND TERMINOLOGY

The surficial deposits of the Elsmere 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). Nearly all surficial deposits in the map area 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 0.083 in. (2 mm) are referred to as pebble size or cobble size, as the case may be. Clast, as used here, refers 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 0.083 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 2.

CHRONOLOGY

The sidereal age limits adopted for early, middle, and late Pleistocene time (see Quaternary time chart) are 1806–778 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 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 geochronology is a work in progress and divisions of the epoch are not yet 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.

Table 2. Sediment colors and corresponding Munsell Soil Color Chart notations.

Unit Color	Hue, Value/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	10YR6/2
pale brown	10YR6/3
light yellowish brown	10YR6/4
very pale brown	10YR, 7/3 and 8/3

The ages assigned to most surficial deposits of the Elsmere quadrangle are estimates based chiefly on stratigraphic relations, position in the landscape, and differences in degree of soil-profile development. Degree of soil development refers to attributes such as thickness, horizon complexity, soil structure, quantities of translocated clay or calcium carbonate, depth of leaching, and so forth. On stable surfaces (those not significantly modified by either erosion or deposition), soil development generally produces more complex and thicker horizon sequences with time, proceeding from thin, simple A/C profiles to more complex, thicker A/B/C profiles (Fig. 4).

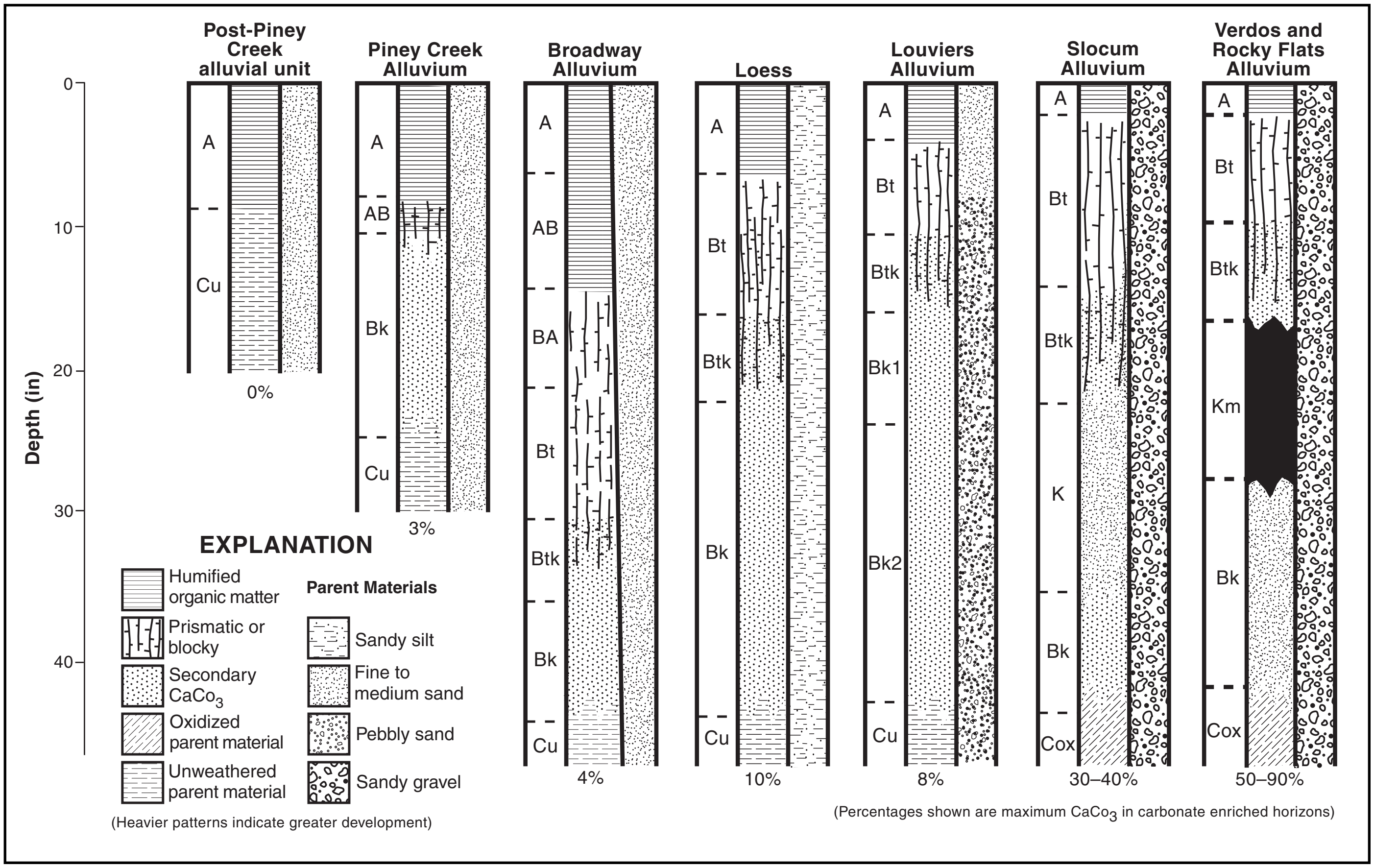


Figure 4. Diagram illustrating progressive increase (left to right) in degree of soil development with increased age in the Lafayette quadrangle, which is just north of Denver. See Table 3 for explanation of soil-horizon nomenclature. Diagram is from Machette (1977), modified slightly by Madole (1991)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

Table 3. Explanation of soil nomenclature.

Horizon	Characteristics (after Soil Survey Division Staff, 1993; Birkeland, 1999)
A	Characterized by an accumulation of humified organic matter intimately mixed with the mineral fraction and not dominated by properties characteristic of E or B horizons.
AB	Transitional horizon between A and B horizons, the properties of which are more like the A horizon than the B horizon.
BA	Transitional horizon between A and B horizons, the properties of which are more like the B horizon than the A horizon.
AC	Transitional horizon between A and C horizons, the properties of which are more like the A horizon than the C horizon.
BC	Transitional horizon between B and C horizons, the properties of which are more like the B horizon than the C horizon.
Bt	Characterized by the accumulation of silicate clay that either formed in place or was translocated downward within or into the horizon. Thus, the horizon has more clay than the deposit in which it formed (parent material) and more than the overlying horizons from which clay was translocated.
Bk	Characterized by an illuvial (translocated) accumulation of alkaline earth carbonates, mainly $CaCO_3$.
Btk	Has characteristics of both Bt and Bk horizons.
Bw	Characterized by the development of color or soil structure or both, with little or no apparent accumulation of illuvial material.
K	A subsurface horizon so impregnated with carbonate that its morphology is determined by the carbonate (Gile and others, 1965; Birkeland, 1999)
Km	A K horizon that is more than 90% cemented by carbobnate.
C	Horizons or layers, excluding hard bedrock, that are little affected by soil-forming processes and lack properties of A, E, or B horizons.
Cox	Oxidized C horizon (Birkeland 1999).

DESCRIPTION OF SURFICIAL MAP UNITS

SURFICIAL DEPOSITS

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

af **Artificial fill (late Holocene)—**Sand, silt, clay, and rock debris emplaced for roadbeds, railroads, parking lots, dikes, embankments, earthen dams, and construction sites for residential and commercial buildings. In sec. 23, T. 14 S., R. 66 W. and secs. 3 and 10, T. 15 S., R. 65 W., artificial fill has been used to bury flood plains and adjacent low terraces to provide building sites for residential subdivisions. Urbanization is so complete in sec. 23 that it is not possible to distinguish between fill and unmodified ground. Hence, the geology of this area was mapped from aerial photography that predated urbanization. Here residences in areas of Qay_1 and some Qay_2 are probably on artificial fill. Unit is generally 3–30 ft thick.

ALLUVIAL DEPOSITS—Sand, silt, gravel, and clay transported and deposited by flowing water in channels or as unconfined runoff or sheet flow. Deposits resulting from sheet flow are referred to as sheetwash alluvium. Sheetwash alluvium exists primarily in sheets and wedges along valley sides and footslopes. Stream alluvium is the principal deposit underlying flood plains and stream terraces.

Qay_1 **Young alluvium one (late Holocene)—**Chiefly light-brownish-gray, grayish-brown, and dark-grayish-brown, poorly sorted sand, silty sand, and minor pebble gravel. Clayey sediment is insignificant compared to sandy sediment, except along small streams that drain areas underlain by Pierre Shale. Unit is present in all valleys, but where Qay_1 is too narrow to show separately, it is included in Qay or Qay_2. Qay_1 is present on narrow flood plains and the floors of stream channels, most of which are incised, and it also blankets Qay_2 in areas adjacent to incised channels and over a broad fan-shaped area along the east edge of the quadrangle. The time of channel incision has not been documented. However, it may correlate with an interval of arroyo cutting, discussed in numerous studies (for example, Bryan, 1925; Graf, 1987; McFadden and McAuliff, 1997), that occurred across much of the southwestern United States in the latter part of the 19th century. Qay_1 generally lacks soil development. Areas of Qay_1 are subject to frequent flooding. Exposed thickness is 2–8 ft.

Qay_2 **Young alluvium two (late and middle? Holocene)—**Sediment is similar to that of Qay_1, except that it includes several thin beds and lenses of dark-grayish-brown to very dark-grayish-brown sediment, some of which are silty and clayey. The layers of dark sediment are extensive, but discontinuous, and probably include both buried soils and slackwater or wetland deposits. Qay_2 blankets large areas on broad valley floors, such as those in the Jimmy Camp Creek drainage basin. Commonly, Qay_2 is overlapped by Qay_1 near stream channels, and, farther from these channels, Qay_2 overlaps Qam. Thus, in places, Qay_1, Qay_2, and Qam exist at the surface, essentially side by side at nearly the same level. In the northern part of the map area, the upper surface of Qay_2 is usually 10–15 ft higher than stream channels, and in the southern part of the area, it is as much as 20 ft higher. In the main valleys, Qay_2 typically forms a veneer over thick sections of Pleistocene alluvium, which may be of more than one age. In the Jimmy Camp Creek drainage basin, the combined thickness of Qay_2 and older, underlying alluvium is 50–80 ft (Jenkins, 1964). A very weakly developed soil, 6–18 in. thick, has formed in this unit. Three ^{14}C ages indicate that Qay_2 was deposited sometime between 4510 and 1280 cal yr B.P. (Table 4). Two of the ages (3900 ± 60 and 2960 ± 60), which are of buried soils about 8 ft below the ground surface at two different localities, provide a maximum age of 4510–4150 cal yr B.P. A single ^{14}C age (1360 ± 60) of a soil developed in the top of Qay_2 where is is buried by about 4 ft of Qay_1 provides a minimum age of 1510–1280 cal yr B.P. Areas of Qay_2 are subject to infrequent large floods, such as occurred in Jimmy Camp Creek on June 17, 1965. Discharge during the 1965 flood was estimated to have reached

Table 4. Conventional[1] radiocarbon ages and corresponding tree-ring calibrated ages[2] of organic-rich sediment in unit Qay_2 at two localities in the Jimmy Camp Creek drainage basin.

Locality[3]	Stratigraphic Unit	Method[4]	Laboratory[5] Sample No.	Radiocarbon Age ± 1σ (^{14}C yr B.P.)	$\delta^{13}C$ (‰)	Calibrated Age ± 2σ (cal yr B.P.)
1B	Qay_2	RAD	Beta-165411	1470 ± 60	-18.0	1510–1280
1A	Qay_2	RAD	Beta-165412	3900 ± 60	-14.7	4510–4150
2	Qay_2	RAD	Beta-166883	2960 ± 60	-15.1	3330–2940

[1]Conventional radiocarbon age; i.e., corrected for isotopic fractionation but not reservoir effects. Age was calculated using a half-life of 5568 years. The ± 1σ standard deviation represents the combined error in counting the radioactive disintigration of the modern standard, the background, and the sample

[2]INTCAL98 (Stuiver and others, 1998) is the database used for calibration

[3]See map for smple locations. 1B and 1A are from the same locality; sample depths below surface are ~4 ft and ~8 ft, respectively

[4]RAD—Radiometric, as opposed to accelerator mass spectrometer

[5]Beta—Beta Analytic Inc., Miami Florida

nearly 124,000 ft^3/sec (Snipes and others, 1974) and had a discharge per unit area that was several times greater than the Plum Creek flood that devastated parts of metropolitan Denver on June 16, 1965 (Jonathan Friedman, oral commun., 2001). The estimated thickness of unit Qay_2 is 10–20 ft.

Qay

Young alluvium, undivided (Holocene)— Unit consists of Qay_1 and Qay_2 undivided because exposures are poor or deposits of the two units are too small to show separately at the scale of this map. Estimated thickness is 10–20 ft.

Qam

Middle alluvium (late Pleistocene)—Light-brownish-gray, pale-brown, light-yellowish-brown, and grayish-brown, poorly sorted sand, silty and clayey sand and, in most places, subordinate amounts of fine gravel. Unit underlies a terrace that, except along Fountain Creek (southwestern part of area), is only slightly higher (3–5 ft) than the upper surface of Qay_2. Along Fountain Creek, the upper surface of Qam is 40–50 ft higher than the creek and 30–40 ft higher than the upper surface of Qay_2. Also, Qam contains more and coarser gravel in this area than it does elsewhere. Unit Qam is believed to underlie Qay_2 in many places. However, in the upvalley part of the abandoned paleovalley on Peterson Air Force Base, Qam is at the surface and is overlain by little, if any Qay_2. Where Qay_2 and Qam are nearly at the same level, they are easily distinguished by the soils developed in them. An A/C soil profile is developed in unit Qay_2, whereas A/Bw/BC/C, A/BA/Bt/BC/C, and A/AB/Bt/Bk/C profiles are developed in unit Qam (see Fig. 4 and Table 3 for explanations of soil-horizon nomenclature). Those deposits of Qam having soil profiles that include Bt (clay enriched) horizons may be older than the deposits in which A/Bw/BC/C profiles are developed. Estimated thickness is 20–50 ft.

Qao_1

Old alluvium one (middle Pleistocene)— Chiefly pale-brown to strong-brown, extremely poorly sorted, fine to very coarse sand, silty and clayey sand, and gravel. Most gravel is in thin beds that consist dominantly of fine pebbles, although locally some deposits contain small amounts of large cobbles. Unit occupies positions in the landscape that are higher than those of Qam, but are lower than Qao_2. Several deposits, partic—ularly in the southern part of the map area, consist of sediment that was eroded from Qao_2 and deposited at slightly lower levels. In places, Qao_1 may contain deposits of late-middle Pleistocene age (equivalents of Kettle Creek Alluvium and Louviers Alluvium, see correlation diagram). These places include: (1) the southeast side of East Fork Sand Creek; (2) areas between East Fork Sand Creek and

Sand Creek south of U.S. Hwy 24; and (3) the drainage basin of the unnamed tributary to Sand Creek in the northwestern part of the map area. Deposits of Qao_1 are 20–160 ft higher than the channels of major streams. Estimated thickness is 3–30 ft.

Qao_2 **Old alluvium two (middle and early? Pleistocene)—**Sediment is similar to that of Qao_1 and is distinguished from it solely on the basis of position in the landscape and height above stream level. Qao_2 underlies the highest surfaces in the landscape. The distribution of Qao_2 within the Colorado Springs Municipal Airport is partly inferred from 1:24,000-scale soil maps (Larsen, 1981). Most deposits are about 200 ft higher than the channels of major streams. Estimated thickness 10–80 ft.

Qao **Old alluvium, undivided (middle and early? Pleistocene)—**Unit may include deposits of more than one age that are un-divided because exposures are poor and relative-age dating techniques generally are not useful for differentiating them. Over much of the area, a cover of eolian sand prevents comparison of the weathering profiles developed in this unit. Also, it appears that strongly developed soils require more time to form in the quartz-rich, clay-poor parent materials of this unit than in most parent materials and are more susceptible to erosion. At the few places where the unit is exposed, as along Powers Boulevard in the southern part of the map area, relict paleosols appear to be truncated to varying degrees. Unit thickness is unknown, but could be as much as 80 ft.

Qav **Valley-side alluvium, undivided (Holocene and late Pleistocene)—**Chiefly brown to light-yellowish-brown, extremely poorly sorted sand, silty and clayey sand, and minor amounts of gravel, mostly pebble size. Unit exists primarily on valley-side slopes and small alluvial fans, and consists of sheetwash, reworked wind-deposited sediment, and material eroded from and deposited in numerous rills and gullies. Estimated thickness is 3–25 ft.

EOLIAN DEPOSITS—Wind-deposited sediment.

Qes_1 **Younger eolian sand (middle and early Holocene and late? Pleistocene)—**Very pale-brown, pale-brown, and light-yellowish-brown sand. Unit is chiefly fine to very coarse sand that appears to have been deposited in 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 Qes_1, whereas soils of the Valent series (Fig. 4) are developed in most upper Holocene sand in eastern Colorado. Unit thickness is estimated to be 3–20 ft.

Qes_2 **Older eolian sand (late Pleistocene)—**Unit is similar in most respects to Qes_1, except it contains more fine sediment (chiefly silt) than Qes_1 and a thicker more complex soil profile (A/Bt/Bk/C). Soils of the Vona series (Larsen, 1981) are developed in Qes_2 (see Fig. 4 for a comparison of Valent and Vona soil profiles). Unit thickness is estimated to be 3–15 ft.

DESCRIPTION OF BEDROCK MAP UNITS

By J.P. Thorson

Dawson Formation (Upper Cretaceous, Paleocene, and Eocene)—The sedimentary rocks lying immediately above the Laramie Formation were first called Dawson "arkose" (with a lower case "a") by Richardson (1912) from a type locality on Dawson Butte, about 30 mi. northwest of the Elsmere quadrangle, near Castle Rock, Colorado. Richardson (1915, Fig. 3) shows 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, which is northwest of the Elsmere quadrangle (Fig. 2), Thorson and others (2001) mapped three informal members in the upper part of the Dawson Formation (Fig. 6) that Scott and Wobus (1973) described but did not map separately. The nomenclature used herein for the Dawson Formation follows that of Scott and Wobus (1973) and Trimble and Machette (1979a, 1979b) 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).

Upper part of the Dawson Formation (Upper Cretaceous and lower Paleocene)—The upper part of the Dawson Formation is divided into facies unit one ($TKda_1$), facies unit two ($TKda_2$), facies unit three ($TKda_3$), and facies unit four ($TKda_4$). Only facies units $Tkda_1$ and $Tkda_2$ crop out on the Elsmere quadrangle. Facies unit one occurs as a thick "basin edge" deposit close to the mountain front on the western edge of the basin (Pikeview and Monument quadrangles, Thorson and others, 2001, and Thorson and Madole, 2002). Facies one also occurs as a coarse basal unit of the upper Dawson, beneath finer grained facies (Fig. 7), which extends from the Pikeview quadrangle, southeastward into the Elsmere quadrangle. This basal unit makes bold outcrops in the northwest corner of the Elsmere quadrangle (secs. 1, 2, and 12, T. 14 S., R. 66 W.) but thins rapidly to the southeast. Finer grained basinal facies, facies two and facies three, interfinger with, and overlie the coarser mountain front and basal facies. Of these two finer grained facies, only facies two outcrops in the Elsmere quadrangle. Facies four lies above facies three and also does not outcrop in the Elsmere quadrangle. Contacts between facies units within the basin are probably both gradational and interfingering. Figure 6 illustrates the facies relationship between these units. The upper part of the upper Dawson Formation has been eroded away in the Elsmere quadrangle, so that facies two ($TKda_2$) is exposed to the top of the local section. Facies three ($TKda_3$) is projected to occur above facies two ($TKda_2$) further to the north in the Falcon NW quadrangle. Facies four is projected to occur in the northern part of the Falcon NW quadrangle and in the Black Forest quadrangle.

The relationship of the Dawson Formation subdivisions of the Colorado Springs area to the stratigraphy used in Denver area is still uncertain. Trimble and Machette (1979b) summarized the current usage of Arapahoe, Denver, and Dawson Formations (in ascending order) for the greater Denver area. The Arapahoe and Dawson Formations of the Denver area are described as arkosic sandstone, siltstone, claystone and/or minor amounts of conglomerate. Where this lithology underlies the Denver Formation, it is called the Arapahoe Formation. The Denver Formation is composed of claystone, siltstone, sandstone and conglomerate composed primarily of altered andesitic volcanic debris. Where the Denver Formation intertongues and pinches out to the south and east the entire unit, equivalent to all

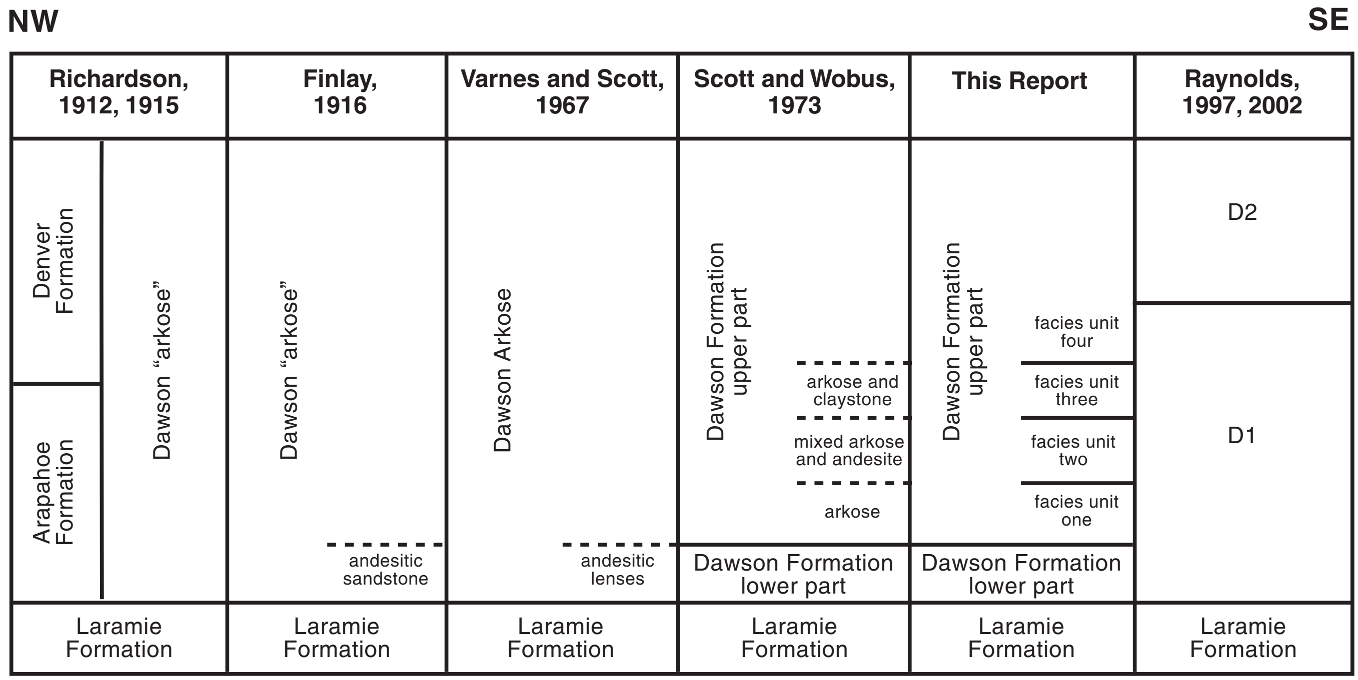


Figure 5. Correlation diagram for subdivisions of the Dawson Formation as used in various publications.

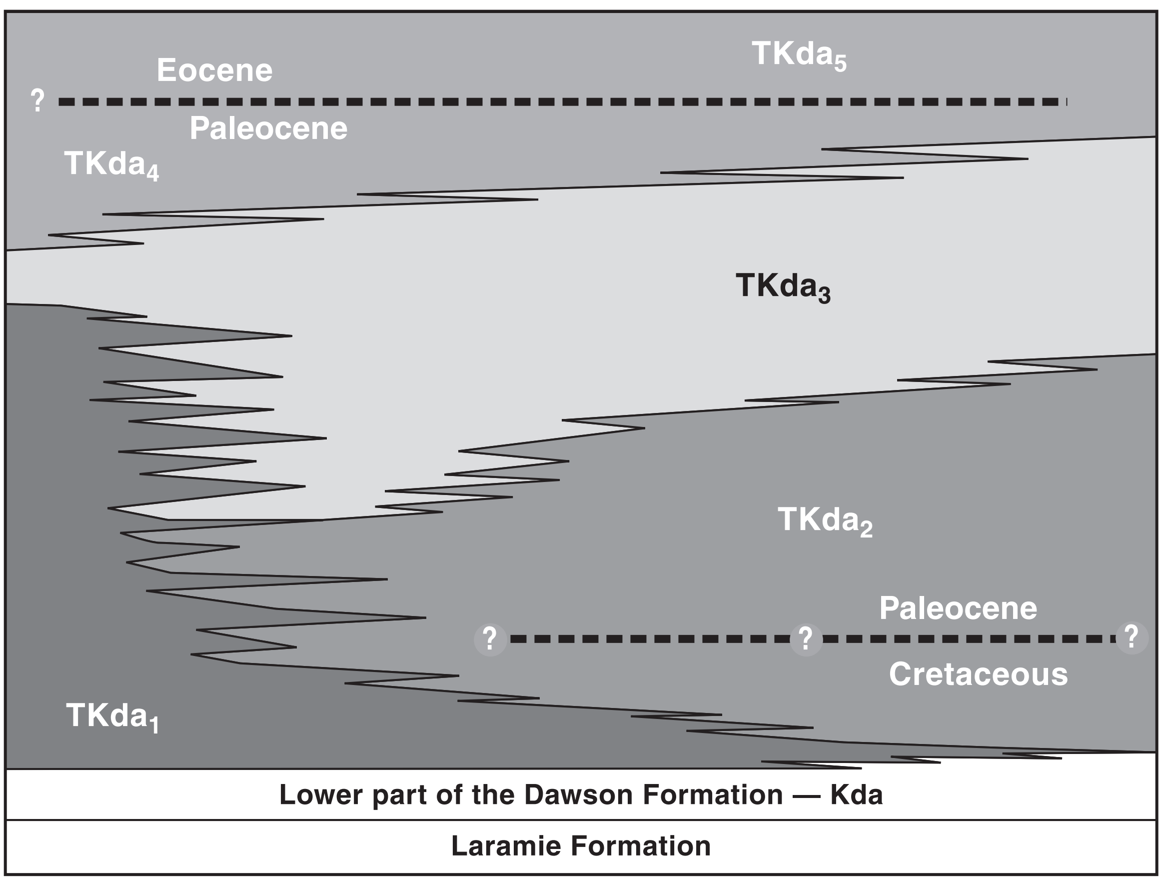


Figure 6. Diagram showing the relationship between facies of the upper part of the Dawson Formation in the Colorado Springs area.

three Denver area formations, is called the Dawson Formation. This understanding has come about through detailed (1:24,000-scale) mapping long the southern edge of the Denver metropolitan area. Scott (1963b) retained the usage Dawson "arkose" for the Kassler quadrangle. Maberry and Lindvall (1972, 1977) show an upper tongue of the Denver Formation that interfingers into the Dawson Arkose. Trimble and Machette (1979b) summarized this relationship and changed the Dawson Arkose to Dawson Formation.

However, it is common practice in the Colorado Springs area to map the andesite-bearing facies unit, here mapped as $TKda_2$, as the Denver Formation (J.W. Himmelreich, Jr., oral commun., 2000). This correlation has largely come about through the usage of the Denver-area formation names (Arapahoe, Denver, and Dawson) for regional aquifer units which have been extended throughout the hydrologic Denver Basin (see for example, Robson, 1987). The extension of the Denver-area aquifer nomenclature throughout the Denver Basin has been done by correlating the electric log signatures of hydrologic units in water wells. The hydrologic units, however, do not correlate with the geologic units (G. D. Vanslyke, oral commun., 2000). The electric logs used for this correlation can be used to separate porous and permeable sandstones and conglomerates from "tight" shales and claystones but they cannot reveal the grain and clast lithologies of the sandstones. In contrast the geologic units are based on lithological criteria, largely the presence or absence of andesitic debris. Thus, the extension of the Denver Formation to Colorado Springs remains suspect, especially since Maberry and Lindvall (1972, 1977) and Trimble and Machette (1979b) describe the Denver Formation as pinching out and intertonging with the Dawson Formation towards the south and east. Furthermore, paleocurrent directions and facies thickness relationships of facies two ($TKda_2$, Fig. 6) suggest that the source for the sediments of this facies was south and west of the Elsmere quadrangle. It is likely that the andesitic conglomerates of the Denver Formation, which are coarser than those of facies $TKda_2$, were transported from a separate source. Crifasi (1992) has analyzed the thickness and sand/shale ratios of the hydrologic units of the Denver Basin and argues for multiple distribution systems in each of the units.

The upper part of the Dawson Formation (unit $TKda_2$) spans the Cretaceous–Tertiary boundary in the Jimmy Camp Creek drainage. (Benson, 1998; Benson and Johnson, 1998; Johnson and Raynolds, 2001). The exact stratigraphic position of the boundary has not been confirmed, but it has been constrained to an interval of about 150 ft of strata. All of the upper part of the Dawson Formation mapped in the Elsmere quadrangle appears to be included within the D1 member of the Dawson Arkose in the Denver Basin proposed by Raynolds (1997; in press; see Fig. 5, this paper) and, therefore, must be no younger than early Paleocene, (R. G. Raynolds, oral commun., 2000). Finlay (1916, p. 10) cites the discovery by G. B. Richardson in 1910 of a mammalian bone within the Elsmere quadrangle in SW 1/4 sec. 2, T. 14 S., R. 65 W. Early Paleocene (Puercan) mammal fossils have also been found in upper Dawson strata in the Corral Bluffs, immediately east of the northeast corner of the Elsmere quadrangle (J.J. Eberle, oral commun., 2001; Middleton, 1983). Thus, the upper part of the Dawson Formation in the Elsmere quadrangle should be considered to be of latest Cretaceous to early Paleocene age. The projected approximate location of the Cretaceous–Tertiary boundary is locally shown on the geological map.

Facies unit four ($TKda_4$) and facies three ($TKda_3$) of the upper part of the Dawson Formation do not outcrop within the Elsmere quadrangle, but they are shown on Figure 5 and 6 to describe the regional stratigraphy of the Dawson. Projections from the adjacent Pikeview, Monument, Black Forest, and Falcon NW quadrangles indicate that facies unit four ($TKda_4$) and facies unit three ($Tkda_3$) can be expected to crop out north of the Elsmere quadrangle and are not present in the subsurface beneath the quadrangle.

$\boxed{TKda_2}$ **Facies unit two—**Facies unit two consists of brownish gray, yellowish gray, and light yellowish brown, pebbly sandstone interbedded with yellowish gray to grayish green, fine- to coarse-grained micaceous sandstone and sandy claystone, and dark gray, greenish gray, and dark brown sandy claystones that contain variable amounts of organic material. About 1,000 ft of strata in the basal part of facies unit two are exposed in the Elsmere quadrangle; the upper part of the unit outcrops beyond the edge of the quadrangle.

The sandstones of facies unit two ($TKda_2$) occur as thick to very thick beds which are poorly sorted, micaceous, and commonly massive or crossbedded. The grains, fine to very coarse sand and pebbles up to about 1.5 in. in diameter, are predominantly quartz with subordinate amounts of feldspar, indicating that the source terrane contained considerable granitic rocks. In many of the pebbly arkose beds and pebble conglomerates, about 30–40 percent of the pebbles consist of greenish gray biotite andesite and hornblende andesite plus minor amounts light gray biotite dacite. The general yellowish gray to yellowish brown "mustard color" weathered color of these strata suggests that the matrix of the sandstones contains considerable montmorillonite clay, derived from the same volcanic source terrane as the andesitic pebbles. Varnes and Scott (1967, p. 16–17) recognized that the clay in the andesitic facies unit two ($Tkda_2$) was different from the clay in the arkosic facies unit one ($Tkda_1$). The clay minerals in white and light gray arkosic beds are chiefly kaolinite, while the clay minerals in yellowish weathering greenish gray andesitic beds are dominantly montmorillonite.

The sandstone and pebble conglomerate beds occasionally contain petrified logs and large fragments of coalified wood. One bed near the stratigraphically highest exposures of facies unit two in the quadrangle contains hundreds of logs up to 4 ft in diameter and tens of feet in length. This bed is well exposed at the top of the Corral Bluffs cliffs just east of the quadrangle boundary. Many of the sandstone and pebble conglomerate beds also contain large clasts (as much as two feet in diameter) of claystone that have been eroded from the beds and banks of channels through which the sands were transported. The logs and claystone clasts indicate that the streams that deposited facies unit two were very energetic and fast flowing. Measurement of the orientation of axes of trough crossbeds and the alignment of petrified logs indicates that most of the streams that deposited sand beds in facies unit two were flowing towards the north or northeast.

Facies unit two contains occasional channels filled with thick beds of light gray pebbly, crossbedded arkose. These light-colored arkoses are the andesite-free arkose lithology of facies unit one ($TKda_1$) but their probable connection to the thicker deposits of facies unit one farther west cannot be demonstrated in this quadrangle. In the Pikeview quadrangle, similar light colored arkoses are interbedded with andesite-bearing beds of mixed source origin (Thorson and others, 2001). The reintroduction of andesite debris into the depositional basin ($TKda_2$), after deposition of the light-colored andesite-free arkoses of facies unit one, was also noted in the Pikeview quadrangle (Thorson, and others, 2001). The depositional patterns and interfingering of andesite-free arkose and andesite-rich sandstone in facies unit two is best explained by different sediment sources and sediment distribution systems. The eastward thinning of facies unit one ($TKda_1$) and generally eastward-directed current directions (Morse, 1979) indicate a westerly and northwesterly source for the light colored andesite-free arkose. The andesite-rich sandstones of facies unit two, however, have current directions that indicate a more southerly or southwesterly source for the mixed arkose and andesite (plus dacite) material (Fig. 7).

Considerable paleontological study of the Jimmy Camp Creek drainage has been done, mostly in facies unit two. Finlay (1916) reported the discoveries of fossil leaves and vertebrates from the area, apparently in part from facies unit two. Knowlton (1922, 1930) and Brown (1943, 1962) have studied the fossil flora and fauna of the Elsmere quadrangle. Benson (1998) described several large collections of Cretaceous and Paleocene fossil leaves from sites along Jimmy Camp Creek. Johnson and Raynolds (2001) collected fossil bones from a crocodilian in adjacent Corral Bluffs, and nearby areas have produced jaws of Paleocene mammals (J.J. Eberle, oral commun, 2001).

During this investigation, fragments of probable dinosaur bone (WP-122, WP-123, WP-124) were found in yellow brown sandstone beds of facies unit two a short distance below the upper Cretaceous fossil leaf sites which constrain the Cretaceous–Tertiary boundary (see following paragraph). Higher in the stratigraphic section and well above the KT boundary, a fossil bone possibly from a large turtle was found in very coarse pebbly arkose (E-108). Fossil roots were discovered near the northeast corner of the quadrangle at location (E-111).

Three fossil leaf collections reported in Benson (1998) and a fourth site described by K. J. Johnson (oral commun., 2001) constrain the KT boundary to somewhere within about 150 ft of strata. At the sites named Lyco–Luck (DMNH-2124) and Kristianity (DMNH-2174, DMNH-2133) large collections of leaves are clearly late Cretaceous in age. Higher up in the section collections from Rainmagnet (DMNH-2131) and Bambi Meets McPhee (DMNH-2133) are early Paleocene. Sampling and identification of palynomorphs by Farley Fleming (quoted in Benson, 1998, p. 123) along Jimmy Camp Creek confirm the restriction of the KT boundary to within about 150 ft. Studies of paleomagnetic orientation of samples from the strata that includes the KT boundary are underway in an attempt to further constrain the location of the boundary (Johnson and Raynolds, 2001; Jason Hicks, oral commun., 2001).

The sandstones and arkoses of facies unit two are generally stable and should have good foundation characteristics. The finer grained, more clay-rich lithologies are less stable and have high shrink-swell potential. The clay-rich shaly lithologies in facies unit two may also be susceptible to landsliding and other forms of downslope mass movement. No evidence of slope failure of these shaly rocks was noted while mapping the Elsmere quadrangle, but future development should be aware of this potential. Facies unit two may be equivalent to the Denver Formation and/or Denver aquifer in the Denver area (J. W. Himmelreich, Jr., oral commun., 2001). Several large springs along Jimmy Camp Creek issue from areas underlain by facies unit two and suggest that the arkoses and sandstones of this facies are good aquifers.

$\boxed{TKda_1}$ **Facies unit one**–composed mostly of white to light gray, crossbedded or massive, very coarse arkosic sandstone, pebbly arkose, or arkosic pebble conglomerate. The unit contains a few 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 unit one comprises the basal strata in the upper part of the Dawson Formation in the northwestern part of the quadrangle, where the unit is between 200 and 300 ft thick. Facies unit one thins east of Sand Creek and is not sufficiently thick to be mapped at a scale of 1:24,000. In Jimmy Camp Creek facies unit one is only about 25 ft thick. Further east the basal white arkose strata can be followed intermittently as far as the center of Sfi sec. 10, T. 14 S., R. 65 W., where it is about 8 ft thick. The arkose beds in facies unit one in the Elsmere

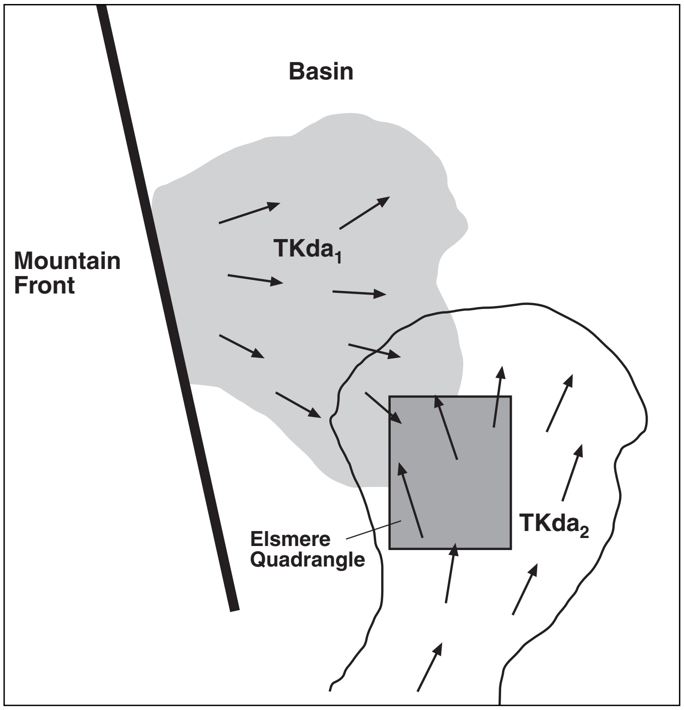


Figure 7. Overlapping depositional systems which resulted in facies units $TKda_1$ and $TKda_2$ of the upper part of the Dawson Formation.

quadrangle are remarkably free of andesitic material, even though the units both above and below are andesite rich. These arkose beds represent the southeastward thinning edge of a wedge or lobe of andesite-free debris that was shed eastward from a granitic source along the western edge of the basin (Fig. 7).

In the northwestern part of the Elsmere quadrangle, and further west in the Pikeview quadrangle, the basal contact of the upper Dawson Formation with the underlying andesitic strata of the lower Dawson Formation is about 30 ft of mixed arkosic and andesitic strata. Exposures of this contact zone in Jimmy Camp Creek (Efi sec. 9, T. 14 S., R. 66 W.) contain several thin beds of white arkosic sandstone inter-bedded with yellowish brown weathering, greenish gray andesitic sandstones, and brown mudstones over a stratigraphic interval of about 135 ft. This relationship indicates that the contact between upper and lower parts of the Dawson Formation becomes more gradational towards the southeast.

Facies unit one is generally permeable, well drained, and has good foundation characteristics. Excavation may be difficult, even though the arkose outcrops are friable on their weathered surfaces. The finer grained interbeds may be less and may have greater shrink-swell properties. The rock fall from cliffs in facies unit one poses a significant slope stability hazard in some residential areas in the northwest part of the quadrangle. Facies unit one may be equivalent to the upper part of Arapahoe Formation and/or Arapahoe aquifer in the Denver area (J. W. Himmelreich, Jr., oral commun., 2001). Two large springs were found to issue from areas underlain by facies unit one and suggest that the arkose beds of this facies are good aquifers.

Kda

Lower part (Upper Cretaceous)—The lower part of the Dawson Formation consists of orange weathering, yellowish green and greenish gray to olive brown sandstone almost exclusively composed of andesitic material and interbedded with grayish green to dark green and brown to brownish gray siltstone and sandy claystone. The lower part of the Dawson Formation is about 320 ft thick in the Elsmere quadrangle.

Sandstone beds in most of the lower part of the Dawson formation are thick to very thick bedded, massive or crossbedded, and fine upward. These sandstones are very poorly sorted and contain a high content of greenish gray clayey matrix apparently derived from the alteration of andesitic debris. The finer grained beds are composed largely of greenish gray clayey material mixed with variable proportions of organic material. Several thin beds of coal and dark brown coaly shale occur in an excellent exposure along the east bank of Jimmy Camp Creek just upstream from Highway 94 (SE1/4SE1/4 sec. 9, T. 14 S., R. 65 W.). This exposure also contains small clastic dikes of light gray sandstone and the petrified stumps of small trees, which were buried upright in their growth positions. The orientations of 35 clastic dikes in the lower part of the

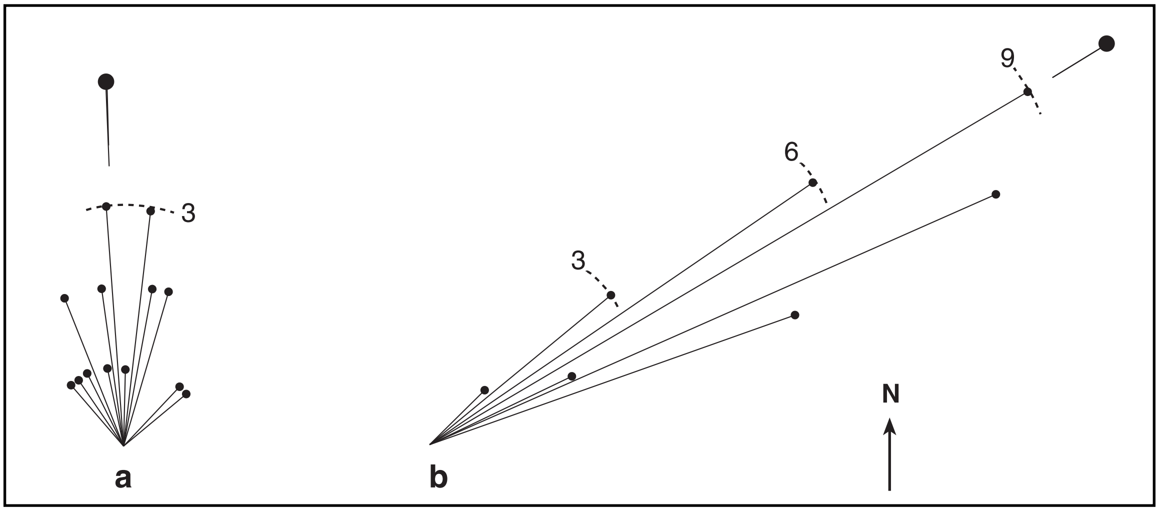


Figure 8. Rose diagrams showing strike of clastic dikes in the Elsmere quadrangle.

Dawson Formation were measured at the Jimmy Camp Creek location and from exposures along Sand Creek (NE1/4 sec. 12, T. 14 S., R. 66 W.). The clastic dikes in the lower part of the Dawson strike closely to N. 60°E., which is in strong contrast to the general north–south orientation of clastic dikes in the Laramie Formation (Fig. 8).

A bed of altered, apparently tuffaceous material, that is now a waxy-textured, grayish green claystone with small white crystals of altered feldspar and small black flakes of biotite, occurs in the Jimmy Camp Creek exposures. Samples of this material were sent to John Obradovich, U. S. Geological Survey, for possible radiometric dating (R. G. Raynolds, oral commun. 2001).

Locally at the base of the lower part of the Dawson there are beds of light gray, medium- to coarse-grained, crossbedded, quartzose pebbly sandstone or chert-pebble conglomerate. The pebbles are subangular to subround, up to about 1.5 in. in diameter, and are mostly white and light gray quartz. This pebbly sandstone and conglomerate is unique in the local section by having a large proportion of black, tan, and orange chert pebbles not seen in similar beds of other units. A smaller proportion of pebbles in these beds are yellow brown and red chert, quartzite, and schist. The lenses of quartzose pebbly sandstone or pebble conglomerate in the base of the lower part of the Dawson Formation are poorly exposed on the west side of the valley of Jimmy Camp Creek just north of Highway 94.

The lower part of the Dawson Formation was deposited in a rapidly aggrading fluvial system carrying sand and clay derived from an andesitic volcanic terrane. Farther to the northwest, in the Pikeview quadrangle, the lower part of the Dawson consists of thick braided-stream deposits of pebbly crossbedded sandstone that contain petrified logs and abundant rip-up clasts of eroded older formations. In the Elsmere quadrangle the lower part of the Dawson represents the distal lower slope portions of a complex of coalescing alluvial fans; farther east it should be finer grained and more clay-rich.

The sandstones in the lower part of the Dawson Formation may have good foundation stability, but the high percentage of clay in the matrix suggests considerable potential for swelling soils. The finer grained units are clearly unstable and have achieved a local reputation as "green slime" for their high shrink/swell potential and significant potential for slope instability (D. C. Noe, oral commun., 2000). No land-sliding of this unit was observed in the field, but this geological hazard should be carefully evaluated when development occurs, particularly in the Jimmy Camp Creek drainage. The lower part of the Dawson Formation, as used on this map and as used by Scott and Wobus (1973), may be equivalent to the lower part of Arapahoe Formation and/or Arapahoe aquifer in the Denver area (J. W. Himmelreich, Jr., oral commun., 2001).

Kl

Laramie Formation, undivided (Upper Cretaceous)—The Laramie Formation was subdivided and mapped as two members by Soister (1968) in the adjacent Corral Bluffs quadrangle (Fig. 9). He mapped a lower member (Kll) dominated by white sandstone, and an upper member (Klu) that is composed of shale, sandstone, and coal. Soister also described a basal, softer and shaly interval within his lower member but did not map these basal strata separately. Thorson and others (2001) recognized the same three subdivisions of the Laramie Formation in the Pikeview quadrangle and were able to map all three units, which they called the lower, middle sandstone, and upper members. All three subdivisions of the Laramie Formation are present in the Elsmere quadrangle, but the basal member is too thin and too poorly exposed to be mapped separately. Therefore, the Laramie Formation is divided into two mappable units (Fig. 9). The upper member (Klu) is correlated to the upper member of Soister (1968) and Thorson and others (2001). The sandstone member (Kls) is correlative to Soister's lower member and to the middle sandstone and lower members of Thorson and others (2001). On the cross section, and in the northwestern part of the quadrangle where the formation has been largely obscured by urban development, the Laramie Formation is undivided.

Klu

Upper member—The upper member of the Laramie is an easily eroded, soft and topographically recessive unit composed mostly of yellowish gray, olive gray, and brownish gray sandy shale which makes poor natural outcrops. This member contains very fine- to medium-grained shaly sandstone, which is usually light gray or yellowish gray and soft, but can be hard where it contains calcareous cement. Sandstone intervals are usually 1–10 ft thick, but bedding within these units is usually very thin (less than 1 in.) and thin (1–4 in.). In the upper Laramie, particularly the uppermost part, sandstone beds are often cemented with limonitic iron oxides that form discontinuous lenticular layers of dark brown to reddish black ironstone. The upper member of the Laramie Formation was deposited mostly on a muddy coastal plain that contained coal swamps, which prograded over the beach-lagoon complex of the underlying sandstone member.

Soister (1968) reported three beds of subbituminous coal, 1–10 ft thick, in the lower 50 ft of the upper Laramie in the Corral Bluffs quadrangle. The distribution of abandoned coal mines indicates that at least two of these beds continue west-

	Soister, (1968)	Thorson and others, (2001)	This Report
Laramie Formation	Upper Member Klu	Upper Member Klu	Upper Member Klu
	Lower Member Klu	middle sandstone member Klu	sandstone member Klu
	basal part (not mapped	Lower Member Klu	basal part (not mapped

Figure 9 . Member-scale subdivisions of the Laramie Formation in the Colorado Springs area.

ward into the Elsmere quadrangle, as they were mined in secs. 14, 15, 16, T. 14 S., R. 65 W. The lowest coal seam (4–8 ft thick) crops out just above the sandstone member of the Laramie in NE1/4SE1/4 sec. 16, T. 14 S., R. 65 W. and at the common corners of secs. 14, 15, 22, 23, T. 14 S., R. 65 W. Coal was also mined in the western part of the Elsmere quadrangle, but the mine sites have been reclaimed and urbanized, so little information is available on the distribution of the coal seams. Locally, the sandstones and shales just above sandstone member of the Laramie have been baked and oxidized to bright red and orange colors where coal beds have burned.

The shales and poorly cemented, fine-grained, shaly sandstones of the upper member of the Laramie Formation can be excavated easily but may have poor stability. The sandstones may have good foundation characteristics, although they may be difficult to excavate. The ironstone layers are the hardest lithology in the upper Laramie but weather into small chips and plates on the outcrops. The upper member of the Laramie Formation is about 225 ft thick.

Kls

Sandstone member—The sandstone member of the Laramie Formation is composed of thick- to very thick-bedded, white, light gray, or light orange, cross-bedded sandstone with small amounts of gray and brown sandy shale and fine-grained sandstone interbeds. The lower Laramie Formation sandstones are fine to medium grained and subangular to subround throughout most of the member, but some of the uppermost beds are coarse grained. Small amounts of mica and dark grains of sand-size chert are characteristic. Outcrops of the lower member are often littered with small spherical concretions of iron-oxide-cemented sandstone 2–3 in. in diameter.

Interbedded in the sandstone member are subordinate softer beds of grayish brown shaly sandstone, which have been intensely burrowed. Some of these burrows are the distinctive form *Ophiomorpha*, commonly interpreted as indicating marine influence. The intensity of the burrowing in some beds, and the amount of preserved organic material in the burrowed beds, suggest a sheltered environment rather than an open, marine environment. Thus, the sandstone member of the Laramie Formation in the Elsmere quadrangle was probably deposited in a barrier beach and lagoonal environment.

The light colored sandstone member of the Laramie Formation makes bold, gently dipping, cuesta outcrops across secs. 14, 15, 16, T. 14 S., R. 65 W. These outcrops are offset and cut by complex sets of N 60°E-trending deformation bands in the SE1/4 sec. 15, T. 14 S., R. 65 W. indicating small faults with normal offset. In several places the upper surface of these gently dipping sandstone outcrops are bedding planes on which clastic dikes of lower Laramie sand, injected into upper Laramie coal or shale, weather in relief. Twenty-two individual clastic dikes were measured near the top of the sandstone member in the Elsmere quadrangle (Fig. 8). These dikes trend generally N–S rather than N 60°E-trend of the clastic dikes in the lower member of the Dawson Formation.

The sandstones of the Kls member have excellent foundation characteristics but may be difficult to excavate. Below cliffs of this unit there may be some risk of rock-fall damage to structures. The Kls member of the Laramie Formation is about 125 ft thick.

Kf

Fox Hills Sandstone (Upper Cretaceous)—The Fox Hills Sandstone is composed mostly of thin to thick beds of very fine- to medium-grained, yellowish gray to yellowish brown sandstone that is micaceous and in part ferruginous. It also contains large brown calcareous concretions up to 5 ft in diameter in the middle and lower parts and thin layers of gray sandy limestone in the basal transition into the Pierre Shale. Thin layers or ledges of iron-oxide-cemented sandstone commonly contain smooth polished pebbles of white to dark brown phosphate and rare shark's teeth. Pelecypod fossils, of probable marine origin, occur in the middle and lower parts. *Ophiomorpha* burrows are common in sandstone beds and are best shown on weathered surfaces of the large concretions. The shales interbedded with the sandstone are olive gray and sandy. The Fox Hills Sandstone was deposited in a shallow marine environment during regression of the Cretaceous sea.

The Fox Hills Sandstone is predominated by hard sandstones that generally have good foundation characteristics, although they may be difficult to excavate. The shales in this unit do not appear to have high swelling potential, nor do they appear to be overly unstable. However, usual care should be taken in evaluating the stability of the shales of this formation. The Fox Hills Sandstone is about 275 ft thick.

Kp

Pierre Shale, undivided (Upper Cretaceous)— The Pierre Shale is composed mostly of gray to dark gray shale that weathers to brown and olive green clay. Its age near Colorado Springs is late early Campanian to early Maastrichtian, on the basis of mapping of ammonite faunal zones by Scott and Cobban (1986). The formation was deposited as marine clay and sand in a shallow epieric seaway. Thickness of the Pierre is about 4,500 ft, but the base of the formation is not exposed in the quadrangle. In the northwestern part of the Elsmere quadrangle, the Pierre Shale is mapped as an undivided unit because urban development largely obscures the area. In the remainder of the quadrangle, the Pierre Shale is subdivided into informal members described by Scott and Cobban (1986), which include the upper part of the upper transition member (Kptu), lower part of the transition member (Kpts), and cone-in-cone zone (Kpc) of Lavington (1933).

The Pierre Shale is easily excavated, but foundation stability is poor. The formation has a high potential for shrink-swell problems due to the presence of smectitic claystone and bentonite beds. The Pierre Shale is also prone to slope instability. Fill material derived from Pierre Shale is not acceptable for use as structural foundation material without special soil treatments (J. L. White, oral commun., 2000).

Kptu

Upper part of the upper transition member— This unit is the uppermost part of the Pierre Shale in the Elsmere quadrangle. These strata are composed of gray to yellowish gray sandy shale and siltstone with scattered thin beds of fine- to very fine-grained sandstone, and a few thin beds of gray sandy limestone.

Kpts

Lower part of the upper transition member—The lower part of the upper transition member of the Pierre Shale is yellowish gray, medium- to coarse-grained sandstone, which is crossbedded and contains thin shale interbeds. These sandstones in the Pierre resemble the sandstone beds in the Fox Hills Sandstone but lack the large calcareous concretions and the phosphate pebbles.

Kpc

Cone-in-cone zone of Lavington (1933)— Most of the upper half of the Pierre Shale is dark gray clayey or silty shale containing reddish brown siderite ironstone concretions, gray iron-stained limestone concretions, thin bentonite beds, and concretions with cone-in-cone structure. This member is about 2,000 ft thick, but its base is not exposed in the Elsmere quadrangle.

LATE CRETACEOUS AND PALEOCENE GEOLOGIC HISTORY

The Elsmere quadrangle is located near the southwestern edge of the asymmetrical, bowl-shaped, geological structure called the Denver Basin (Emmons and others, 1896), which lies immediately east of the Front Range. This structural depression covers most of eastern Colorado north of Pueblo, southeastern Wyoming, and southwestern Nebraska. The sedimentary rocks of the Elsmere quadrangle dip gently northeast towards the axis of this basin. The early geological history recorded by the outcropping rocks of the Elsmere quadrangle can be read from the southwest to northeast, following the dip of the sedimentary rocks, and shown on the cross section that accompanies the geological map.

This geological history begins in the Late Cretaceous about 80 Ma during a time when the interior of North America was flooded by a seaway. The Pierre Shale (Kp, Kpc, Kpts and Kptu), containing mostly open-marine fossils, was deposited on the floor of this sea. Towards the end of the Late Cretaceous, the middle part of North America began to rise and the Cretaceous sea withdrew. As the sea shallowed, the Fox Hills Sandstone (Kfh) was deposited near the shoreline as shallow marine sands, probably as offshore sandbars and sand sheets distributed by storm waves, with nearshore marine fossils and abundant burrowing organisms. The sands that became the sandstone member of the Laramie Formation (Kls) were deposited in a beach and back-beach lagoon environment. The lagoons were gradually filled in by mud and fine sands brought to the edge of the Cretaceous sea by a relatively gentle river system and deposited as a muddy coastal plain at least partly covered by coal swamps. The sediments of this coastal plain became the upper part of the Laramie Formation (Klu). The marginal marine environments (coastal plain, lagoon, beach, and offshore shallow marine) gradually prograded towards the east, filling in the edges of the basin as the sea withdrew.

Near the end of the Cretaceous Period, about 68 Ma, the local environment changed very rapidly. The Front Range began to be uplifted and volcanoes, located somewhere to the southwest, erupted andesite. Although the Elsmere quadrangle did not experience volcanism or major uplift, the resulting sedimentary deposits eroded from the volcanic-covered uplift eventually became the lower part of the Dawson Formation (Kda). In the Elsmere quadrangle the lower Dawson rocks are sandstones and mudstones derived largely from eroded andesite, and they contain petrified stumps of trees which were buried in upright position. Further to the west, in the Pikeview quadrangle (Thorson and others, 2001), the lower Dawson strata contain andesite pebble conglomerates with ripped-up boulders of older formations and stumps and trunks of palm trees. The lower Dawson in the Elsmere quadrangle was deposited on gentle slopes at the eastern edge of a complex of coalescing alluvial fans which were building outward, away from the rising mountains.

As the Front Range continued to rise, the ancient Precambrian core of the mountains (largely Pikes Peak Granite west of the mapped area) was exposed by erosion. The eastern edge of a complex of coalescing alluvial fans containing large amounts of light colored arkose and arkosic pebble conglomerate extended into the Elsmere quadrangle. These deposits became map unit $TKda_1$, facies unit one of the upper part of the Dawson Formation. These light colored arkosic sediments are composed exclusively of granitic debris deposited by high-energy braided streams flowing eastward from the mountains.

At the same time, another river system was bringing sand and mud from a mixed granite-andesite-dacite source area into the depositional basin from the south or southwest. These mixed source sediments became map unit $Tkda_2$, facies unit two of the upper part of the Dawson Formation. The lower part of map unit $Tkda_2$ contains dinosaur fossil fragments, large chunks of coalified trees, and Late Cretaceous leaf fossils. The upper part of map unit $TKda_2$ contains early Tertiary (Paleocene) leaf fossils, trunks and stumps of trees including palms, and fossil bones of small mammals. This episode of the Elsmere geological history ends at about 64.5 Ma, but younger $TKda_2$ strata continue beyond the northern edge of the Elsmere quadrangle. The strata which were deposited during younger parts of the Tertiary Period have been stripped from the mapped area by erosion.

COAL

From an historical perspective coal is the most significant mineral resource in the Elsmere quadrangle. Although mining has ceased in the quadrangle, coal resources may still exist in the Laramie Formation. In the late 1800s and early to middle 1900s, coal mining from seams in the Laramie Formation was a major industry in the Colorado Springs area. Coal production in the region was first recorded in 1882 from the Franceville Mine in the Corral Bluffs quadrangle just east of Elsmere. The McFerran Mine in northeastern Elsmere quadrangle (secs. 10 and 15, T. 14 S., R. 65 W.), which began production in 1885, was the second commercial operation (Goldman, 1910). A total of 378,643 tons of coal was produced from underground mines in the Elsmere quadrangle between 1885 and 1941. Production data for coal mines in the Elsmere quadrangle are listed in Table 5. In the northwestern part of the quadrangle, surface indications of this once thriving industry have been largely erased by urbanization. In the eastern part of the quadrangle, minor surface features still remain where the Colorado Division of Minerals and Geology has closed mine openings. The locations of most of these reclaimed openings are marked with brass caps on iron pipe monuments. Subsidence risks over the mined-out areas of the Elsmere quadrangle have been assessed for the Colorado Department of Natural Resources (Dames and Moore, 1985). Maps portraying some of the subsidence risks can be examined at the offices of the Colorado Geological Survey. A summary map of subsidence risk areas is included in Turney and Murray-Williams (1983).

Kirkham (1978) tabulated available data on the quality of coal from the Jimmy Camp and Kurie mines, which are probably representative of the coal in the Elsmere quadrangle. In 11 samples, moisture varied from 17.3–23.1 percent; volatile matter, 30.9–44.6 percent; ash, 5.6–11.7 percent; and sulfur, 0.4–0.6 percent. Heat values for these samples vary from 8960–12,950 BTU/lb. Laramie Formation coal generally ranks as subbituminous B to subbituminous C.

OIL AND GAS

The Colorado Oil and Gas Conservation Commission has records for two petroleum test wells drilled in the Elsmere quadrangle. In 1954 Peterson and Mickleson drilled the No. 1 Raymond Lewis well (center SW 1/4 NW 1/4 sec. 23, T. 14 S., R. 65 W.) to a depth of 6,868 ft to test the Permian Lyons Sandstone. Drill stem testing in the Lyons Sandstone at a depth of 6,733–6,776 ft returned only mud and fresh water. An additional drill stem test in the Cretaceous Dakota Formation at 5,823–5,878 ft returned slightly gas-cut water. Also in 1954, the Sinclair Oil and Gas Co. drilled the Sinclair No. 1 R. W. Lewis (NW 1/4 NW 1/4 NW 1/4 sec. 2, T. 14 S., R. 65 W.) to a depth of 7,600 ft as a test of the "D" and "J" sands of the Dakota Formation. A drill stem test in the Dakota at 7,468–7,500 ft depth returned only muddy water. Both of these holes were wildcats and were subsequently plugged and abandoned. The drilling companies reported formation tops as shown in Table 6. Electric logs of these wells are available at the Colorado Oil and Gas Conservation Commission. No petroleum production has been reported in the Elsmere quadrangle. The nearest oil production is from the Florence oil field in the Canon City Basin, 30 mi. southwest of Colorado Springs, where oil is produced from fractures in the Pierre Shale.

SAND AND GRAVEL

Sand and gravel have been mined at a few localities in the Elsmere quadrangle. No commercial mining is presently in progress, although the Daniels Sand Mix Company operates deep quarries near the west edge of the quadrangle between Security and Sand Creek. Most sand and gravel quarries that were operated previously in the Elsmere quadrangle have been reclaimed and urbanized. Alluvium in the area typically contains only small amounts of gravel that are larger than granule size (>4 mm). Consequently, quarry operators near the southwest corner of the quadrangle (Daniels Sand Mix, Schmidt Construction, and Castle Concrete) have produced aggregate by mixing sand from local pits with coarse gravel and quarry rock obtained from other localities (Schwochow and others, 1974).

Most of the alluvium in the Elsmere quadrangle was derived from the Dawson Formation. Elsewhere in the Colorado Springs area, alluvium derived from this formation has been mined because it contains large amounts of clean (minimal silt and clay), coarse-grained sand that consists chiefly of quartz (that is, has a high silica content). Uses for the sand include glass making, hydraulic fracturing of oil-field reservoirs, blast sand, well-pack sand, filter sand, pipeline sand, and engine sand (Schwochow and others, 1974). Some of the alluvium in the Elsmere quadrangle may be suitable for these uses.

Table 5. Reported production data for coal mines within the Elsmere quadrangle (from Kirkham, 1978, and Turney and Murray-Williams, 1983).

Mine Name	Location	Seam Thickness (feet)	Reported Dates of Operation	Total Known Production (tons)
Cardiff	SW¼SE¼ sec. 2, T. 14 S., R. 66 W.	2.5	1896	1,000
Enterprise	SW¼NW¼ sec. 12, T. 14 S., R. 66 W.	2.5	1905–1906	6,120
Hall Slope	SW¼NE¼ sec. 12, T. 14 S., R. 66 W.	?	?	none reported
Jimmy Camp	NE¼NW¼SE¼ sec. 16, T. 14 S., R. 65 W.	4.9–5.9	1929–1941	76,786
Kurie	SW¼NW¼NE¼ sec. 14, T. 14 S., R. 65 W.	5.0	1929–1933	45,419
McFerran	SW¼SE¼ sec. 10;	7.0	1885–1896	219,792
	SE¼NW¼ sec. 15, T. 14 S., R. 65 W.			
Tudor	SE¼SW¼ sec. 2, T. 14 S., R. 66 W.	5.5	1903–1907	29,526
Total coal production from Elsmere quadrangle (tons)				**378,643**

Table 6. Formation tops reported for petroleum test wells drilled in the Ellesmere quadrangle.

Peterson and Mickleson No. 1 Raymond Lewis Sec. 23, T. 14 S., R. 65 W.		**Sinclair Oil and Gas No. 1 R. W. Lewis Sec. 2, T. 14 S., R. 65 W.**	
Datum	**(KB Elev. 6031 ft)**	**Datum**	**(Ground Elev. 6548 ft)**
Pierre	150		
Niobrara	4890	Niobrara	6580
Ft. Hays	5280	Ft. Hays	7012
Codell	5430	Codell	7060
Carlile	5440	Carlile	7074
Greenhorn	5529	Greenhorn	7174
Graneros	5698	Dakota D sand	7456
Bentonite	5726	Dakota J sand	7502
Dakota D sand	5825	Skull Creek	7570
Dakota J sand	5878	**Total Depth**	**7600**
Skull Creek	5844		
Lakota	6008		
Morrison	6070		
Red Beds	6446		
Lyons	6722		

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