OPEN-FILE REPORT 03-09

Geologic Map of the Greenland Quadrangle, Douglas and El Paso Counties, Colorado

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With a section on Geological Hazards
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FOREWORD

The Colorado Department of Natural Resources is pleased to present the Colorado Geological Survey Open-File Report 03-9, *Geologic Map of the Greenland Quadrangle, Douglas and El Paso Counties, Colorado.* Its purpose is to describe the geologic setting and mineral resource potential of this 7.5-minute quadrangle located along the I-25 corridor about 40 miles south of Denver. Dr. Jon P. Thorson, contract geologist for the Colorado Geological Survey, completed the field work on this project in the summer of 2002.

This mapping project was funded jointly by the U.S. Geological Survey (USGS) and the Colorado Geological Survey (CGS). USGS funds are competitively awarded through the STATEMAP component of the National Cooperative Geologic Mapping Program (Agreement No. 02HQAG0050). 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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INTRODUCTION

The Greenland 7.5-minute quadrangle is located between Colorado Springs and Castle Rock, Colorado, in the southern part of the Colorado Piedmont section of the Great Plains (Fig. 1). The Colorado Piedmont is distinguished by having been stripped of the Miocene fluvial rocks (Ogallala Formation) that cover much of the Great Plains. The Greenland quadrangle is located in the upper parts of the West Cherry Creek and Plum Creek drainage basins, which are tributaries to the South Platte River.

Geologic mapping of the Greenland 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 ground-water evaluation. Figure 2 shows the location of the Greenland quadrangle and the status of geologic mapping of 7.5-minute quadrangles in the Colorado Springs area.

This map is based on prior published and unpublished geologic maps and reports, interpretation of aerial photography, and field mapping in 2002. Two sets of aerial photographs were used: 1:28,000 scale black and white photographs taken in 1969, and 1:40,000 scale color infrared

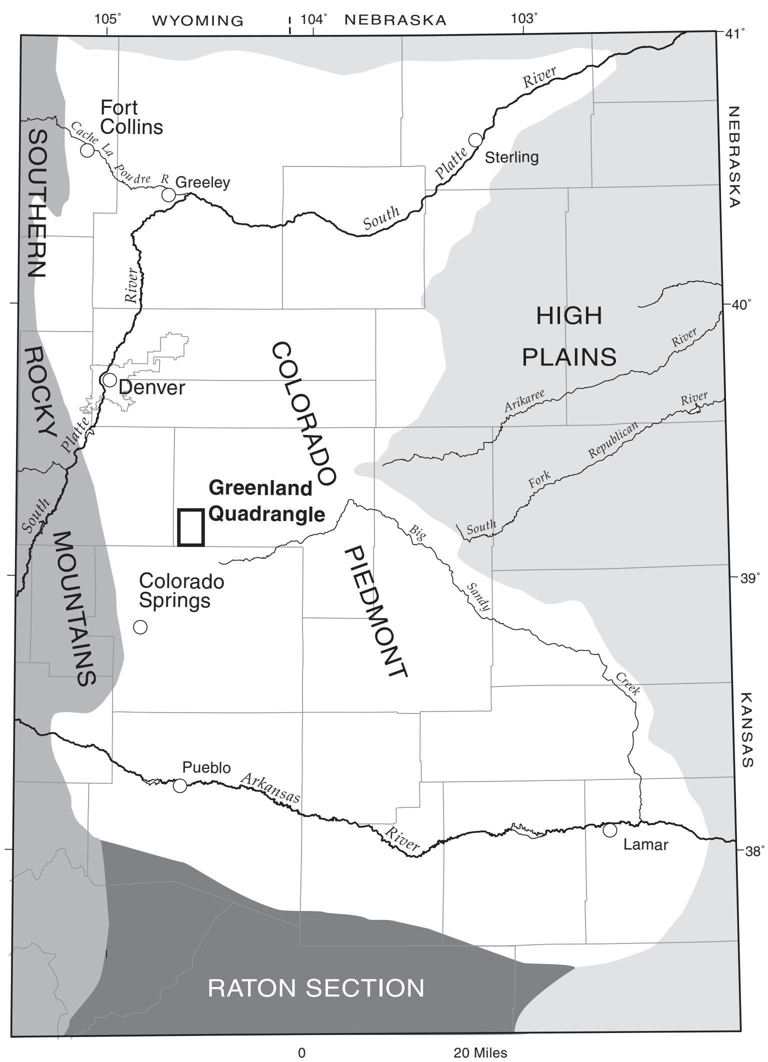
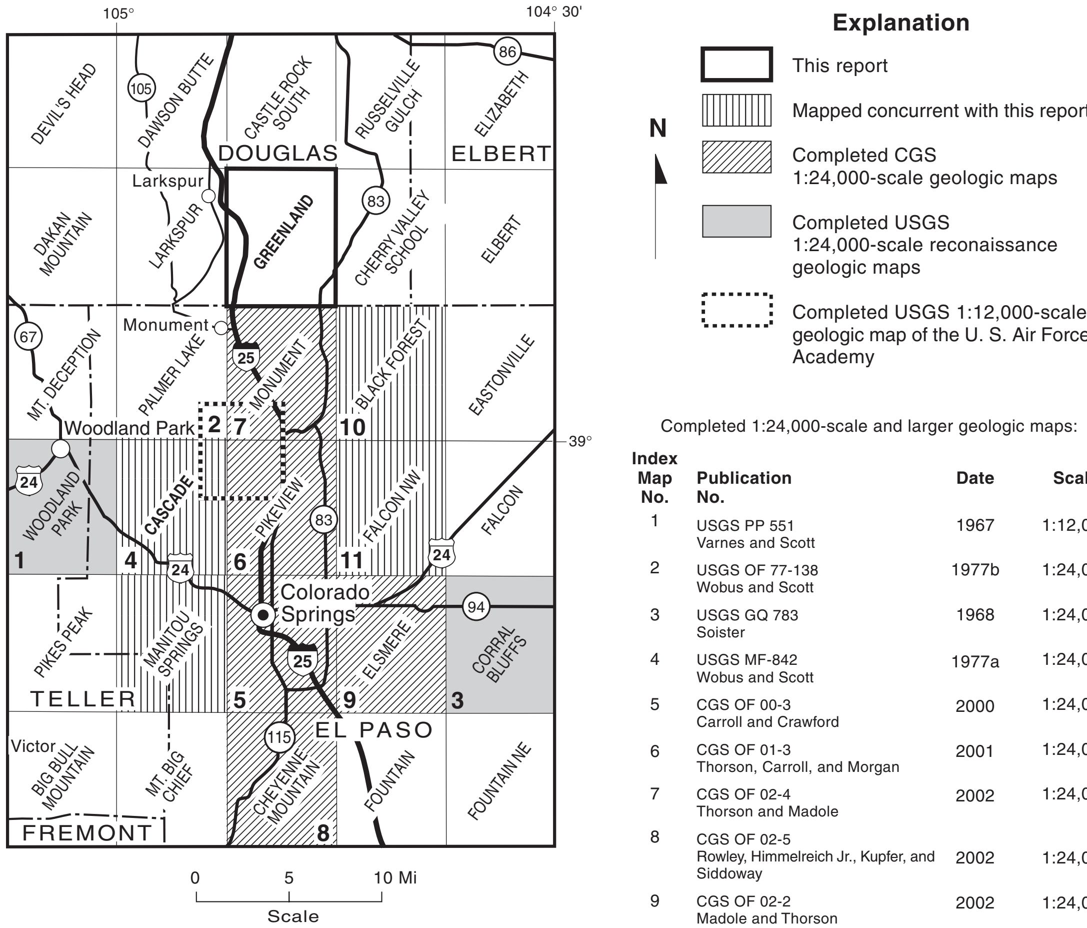


Figure 1. Map showing the location of the Greenland quadrangle with respect to the Southern Rocky Mountains and the Colorado Piedmont, High Plains, and Raton sections of the Great Plains defined by Fenneman (1931) and modified from Madole (1991).



Completed 1:24,000-scale and larger geologic maps:

Index Map No.	Publication No.	Date	Scale
1	USGS PP 551 Varnes and Scott	1967	1:12,000
2	USGS OF 77-138 Wobus and Scott	1977b	1:24,000
3	USGS GQ 783 Soister	1968	1:24,000
4	USGS MF-842 Wobus and Scott	1977a	1:24,000
5	CGS OF 00-3 Carroll and Crawford	2000	1:24,000
6	CGS OF 01-3 Thorson, Carroll, and Morgan	2001	1:24,000
7	CGS OF 02-4 Thorson and Madole	2002	1:24,000
8	CGS OF 02-5 Rowley, Himmelreich Jr., Kupfer, and Siddoway	2002	1:24,000
9	CGS OF 02-2 Madole and Thorson	2002	1:24,000
10	CGS OF 03-6 Thorson	2003	1:24,000
11	CGS OF 03-8 Madole	2003	1:24,000

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

photographs taken in 1988. The topographic base map for the Greenland quadrangle was published in 1954 and updated by photo inspection in 1969. Consequently, some of the presently existing roads, buildings, and other human-made modifications of the landscape are not shown on the base map.

Previous geological mapping in the Greenland area includes the work of Emmons and others (1896) and Richardson (1915). Scott and Wobus (1973) mapped the Colorado Springs area, which is south of the Greenland quadrangle, in reconnaissance fashion and published a geological map at a scale of 1:62,500. Trimble and Machette (1979a) published a 1:100,000 scale regional geologic map of the Front Range urban corridor which includes the Greenland quadrangle.

The names and symbols used for geological units in the Greenland quadrangle conform as much as possible to those employed previously on geologic maps of nearby areas prepared by the Colorado Geological Survey (Fig. 2). 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. Some of the surficial deposits of the

Greenland quadrangle are not well exposed. Consequently, the thickness of most units is estimated and descriptions of physical characteristics such as texture, stratification, and composition are based on observations at a limited number of localities.

ACKNOWLEDGEMENTS

This mapping project was funded jointly by the Colorado Geological Survey and the U.S. Geological Survey through the National Geological Mapping Program. Many people have earned my thanks: Vincent Matthews of the Colorado Geological Survey; Robert G. Raynolds, Denver Basin Project, Denver Museum of Nature and Science; and John W. Himmelreich, Jr., John Himmelreich and Associates, Inc., Colorado Springs, reviewed the map and text. Matt Morgan and Karen Morgan of the Colorado Geological Survey were valuable help in converting notes and field mapping on aerial photos into the geological map. George D. VanSlyke, Colorado Division of Water Resources, provided generous access to his department's files of water-well logs. Jane Ciener served as technical editor. Special thanks go to the landowners and developers who granted permission to enter their property.

GEOLOGIC SETTING

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

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

Intense weathering developed a regional paleosol horizon across the Denver Basin during upper Dawson deposition in the late Paleocene (Farnham 2001a, 2001b; Farnham and Kraus, 2002; Nichols and Fleming, 2002; Raynolds, 2002). This paleosol was proposed to be the boundary between the Paleocene and Eocene Epochs by Soister and Tschudy (1978), but the recent work cited above has shown that the paleosol formed in the late Paleocene shortly after the creation of an unconformity that is recognized as the boundary between the Dawson D1 and D2 sequences (R.G. Raynolds, 2003, written commun., see Fig. 3). In the Monument and Black Forest quadrangles (Thorson and Madole, 2002; Thorson, 2003), the projected location of the strongly developed paleosol was used as the boundary between Dawson facies units four and five. After the period of landscape stability and weathering, mountain uplift resumed and Dawson facies unit five ($TKda_5$), was deposited in the basin. Although the regional paleosol horizon crops out in the adjacent Dawson Butte and Larkspur quadrangles, it has not been found in the Greenland quadrangle (Raynolds, 2002, personal commun.); it and the late Paleocene unconformity probably remain unexposed beneath surficial deposits. Consequently, the Dawson exposed in the Greenland quadrangle appears to be entirely facies unit five. The uppermost part of this facies unit was removed by an extended period of erosion in the late Eocene.

Following the erosion of some of the upper part of the Dawson Formation, the conglomerate of Larkspur Butte (Thorson, 2003) was deposited in a series of channels and broad valleys occupied by streams that drained the newly rejuvenated mountains. In the western part of the Greenland quadrangle the conglomerate of Larkspur Butte was deposited in narrowly confined, steep-walled stream valleys. These valleys became broader towards the southeast.

The Wall Mountain Tuff, an ignimbrite or glowing hot volcanic ash flow, was erupted in the late Eocene and flowed across the landscape. This ash flow blanketed the eroded surface of the Dawson Formation and the valleys that contained the conglomerate of Larkspur Butte. Because of its great heat, the ash compacted into a viscous plastic that flowed for short distances

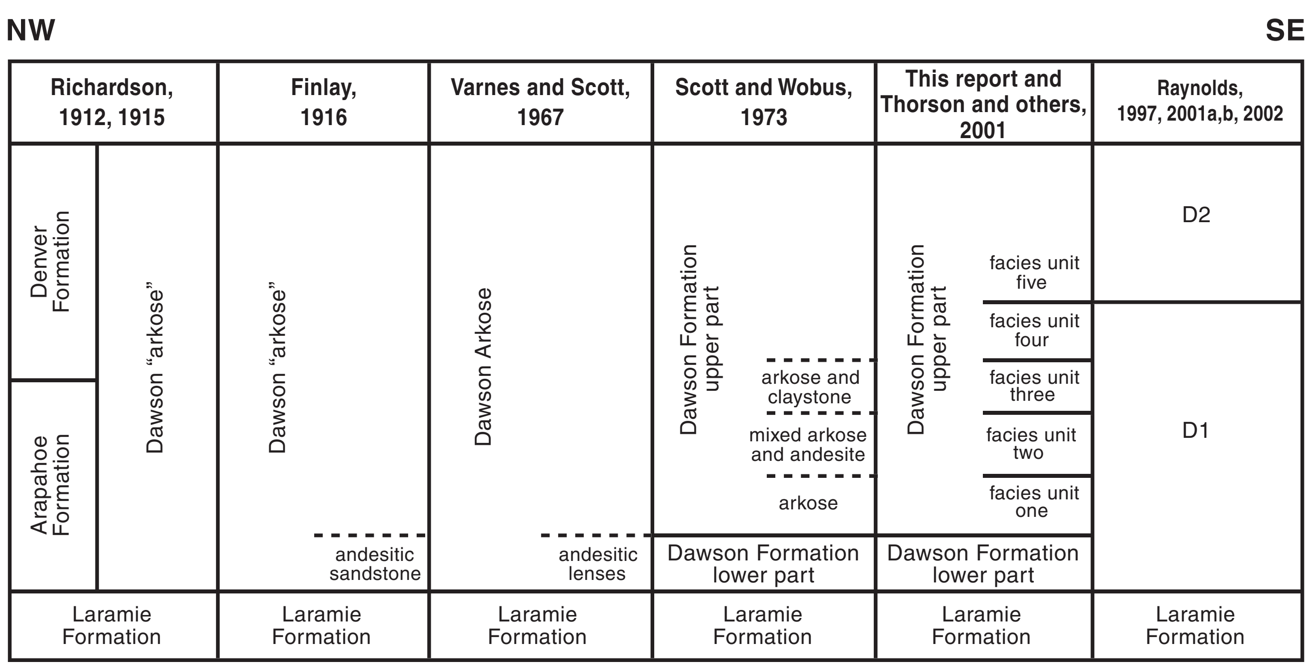


Figure 3. Nomenclature diagram for subdivisions of the Dawson Formation as used in various publications pertaining to the Colorado Springs area.

before it cooled into welded tuff. Erosional remnants of the Wall Mountain Tuff now cap the conglomerate of Larkspur Butte on the higher buttes in the Greenland quadrangle. The Castle Rock Conglomerate was deposited near the end of the Eocene in paleovalleys on an erosion surface that cuts across the upper Dawson, conglomerate of Larkspur Butte, and Wall Mountain Tuff.

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

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 the type locality on Dawson Butte about 5 mi northwest of the Greenland quadrangle. Richardson (1915, Fig. 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. Scott and Wobus (1973) recognized that some of the upper part of the Dawson contains considerable andesitic debris in the Colorado Springs area (facies unit $TKda_2$, Thorson and others, 2001; Thorson and Madole, 2002; Madole and Thorson, 2002; Madole, 2003) but did not map this material as a separate unit. Morse (1979), however, combined observations from the andesitic lower Dawson with observations from andesitic parts of the upper Dawson without reference to locality. Recent work by the Denver Museum of Nature & Science (Raynolds, 2002) has shown that the Dawson Formation can be divided into two unconformity-bounded sequences designated D1 and D2 (Fig. 3). The unconformity that separates these sequences has been shown by Nichols and Flemming (2002) to separate early Paleocene pollen zone P3 from late Paleocene pollen zone P6. The rocks mapped in this report as $TKda_5$ are part of the younger D2 sequence.

In areas near the Greenland quadrangle, five informal facies unit members of the Dawson Formation are now recognized (Fig. 3). The nomenclature used for the Dawson Formation, in this work and the above references, 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).

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 southwestern edge of the basin has not been determined. 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). Fossil leaf localities in the Monument quadrangle (Scotty's Palm, Denver Museum of Nature & Science, DMNH-1204, NE 1/4 SW 1/4 sec. 12, T. 12 S., R. 67 W., Johnson, 2001; and Baptist Road, Denver Museum of Nature & Science, DMNH-2177, NW 1/4 sec. 35, T. 11 S., R. 67 W., Johnson and Raynolds, 1998) are Paleocene in age. 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 the regional paleosol traced around the basin by Soister and Tschudy (1978) and proposed to mark the Paleocene–Eocene boundary. This paleosol was used as the boundary between Dawson facies units four and five in the Monument quadrangle. Recent work on this paleosol has recognized that it separates early Paleocene pollen zone P3 from late Paleocene Pollen zone P6 (Nichols and Fleming, 2002).

CONGLOMERATE OF LARKSPUR BUTTE

The conglomerate of Larkspur Butte (Tlc) is a newly recognized unit of probable late Eocene age that underlies the late-Eocene-age Wall Mountain Tuff on Larkspur Butte, and on most of the other high buttes in the Greenland quadrangle. In this report the name “conglomerate of Larkspur Butte” is used informally.

The conglomerate of Larkspur Butte is a brown, pinkish-brown, or pink arkosic conglomerate that was previously included in the top part of the upper Dawson Formation (Richardson, 1915; Trimble and Machette, 1979a; Morse, 1979). It is predominantly composed of pebbles and cobbles of pink granite or pink feldspar in a coarse sand-size to pebble-size matrix of quartz and pink feldspar. Clasts of gray or white quartz are common; less abundant are clasts of gneiss, quartzite, red sandstone, and chert. Large clasts of eroded Dawson Formation arkose, up to 3 ft in diameter, are common near the base of the unit. On Larkspur Butte the unit contains granite clasts up to 8 in. in diameter. The clast size decreases towards the southeast, until in the Black Forest quadrangle the largest clasts are only about 3 in. in largest dimension (Thorson, 2003). Minor interbeds of coarse to very coarse light-brown sandstone occur locally. The unit is strongly cross bedded.

This unit should be mapped as a separate formation and not included as the uppermost part of the upper Dawson Formation for the following reasons:

1. The conglomerate of Larkspur Butte was deposited on a significant erosional unconformity across the top of the Dawson Formation. On Larkspur Butte the Dawson-Larkspur contact cuts downward across about 50 to 60 ft of Dawson strata and appears to be the edge of a steep-walled paleovalley filled with the conglomerate of Larkspur Butte (Fig. 4). The Wall Mountain Tuff rests on the conglomerate of Larkspur Butte over the filled paleovalley but was deposited

directly on the Dawson outside the paleovalley. Similar paleovalley-filling relationships were found on Corner Mountain, Nemrick Butte, Rattlesnake Butte, True Mountain, and the unnamed butte in NE1/4 sec. 7, T. 10 S., R. 66 W.

2. The conglomerate of Larkspur Butte is lithologically distinct from strata above and below. The Dawson strata below the contact are finer grained, predominantly arkose and pebbly arkose that seldom contains pebbles larger than 3/4 in. The Dawson Formation arkose and pebbly arkose also has a very high content of light-colored sandy clay matrix filling intergranular spaces between coarse sand or pebble clasts. The conglomerate of Larkspur Butte is distinctly matrix-poor and has well preserved, empty, intergranular pores between pebble-size clasts. The conglomerate of Larkspur Butte is overlain either by Wall Mountain Tuff or by Castle Rock Conglomerate. The Wall Mountain Tuff is a light-gray, light-brown, or lavender-gray fine-grained welded tuff with small phenocrysts of sanidine and biotite. The Castle Rock Conglomerate is similar to the conglomerate of Larkspur Butte but contains clasts of Wall Mountain Tuff.
3. The conglomerate of Larkspur Butte has a different alteration history than the Dawson. Most of the feldspar in the Dawson, either as individual grains or in granite clasts, has been bleached white, light gray, or cream colored and partially altered to clay by diagenetic or weathering processes. Feldspars in the conglomerate of Larkspur Butte are unaltered and retain the pink, light-red, or reddish-brown color characteristic of the Pikes Peak Granite. The difference in alteration history of these two units suggests that there is significant time represented by the erosional unconformity at the contact. During this time the uppermost Dawson

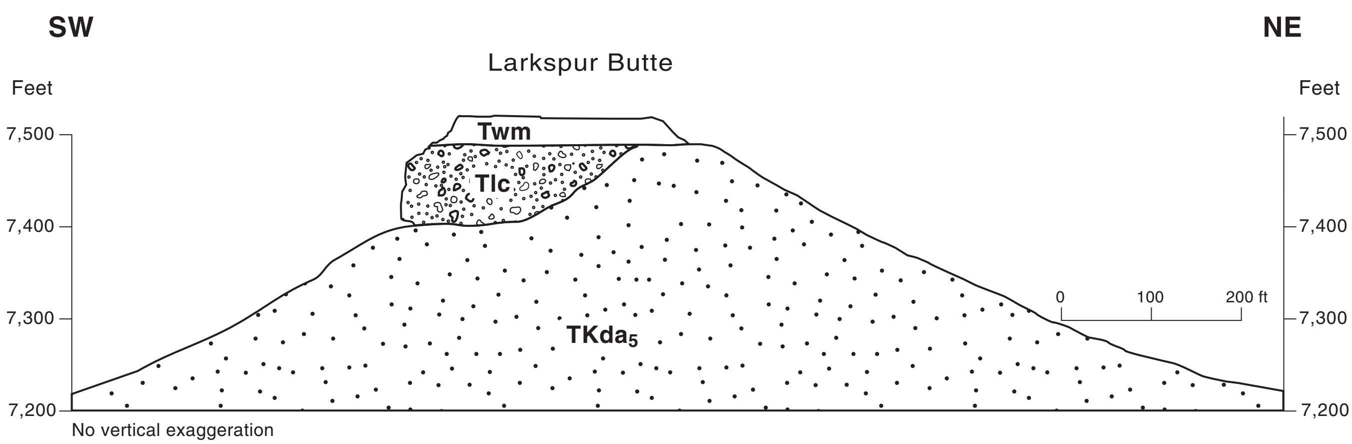


Figure 4. Northeast-southwest sketch cross section of the top of Larkspur Butte showing the relationship between the Dawson Formation (TKda$_5$), the Wall Mountain Tuff (Twm), and the conglomerate of Larkspur Butte (Tlc). The contact between the Dawson and conglomerate of Larkspur Butte is an erosional unconformity that appears to represent the edge of a paleovalley filled with conglomerate.

was deposited, altered, and eroded before the conglomerate of Larkspur Butte was deposited. The bleaching alteration event does not affect any of the rocks younger than the Dawson so it must have been completed before deposition of the conglomerate of Larkspur Butte. Thus, there is a significant (but not yet resolved) age difference between the upper Dawson and the conglomerate of Larkspur Butte.

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

The conglomerate of Larkspur Butte is clearly of Eocene age; it lies between Eocene upper Dawson Formation facies unit five and late Eocene-age Wall Mountain Tuff. It is of probable late Eocene age because a significant part of the Eocene epoch passed during the deposition, alteration, and erosion of Dawson facies unit five. And, because the conglomerate of Larkspur Butte fills, or partially fills, paleovalleys that were present in the late Eocene and appear to have influenced the deposition of the Wall Mountain Tuff.

The distribution of the conglomerate of Larkspur Butte is not yet fully known. It is preserved under a caprock of Wall Mountain Tuff on most of the higher buttes in the Greenland quadrangle. Erosional remnants were mapped on a few other high points, notably in sec. 20, T. 10 S., R. 66 W. and sec. 28, T. 9 S., R. 66 W. A large outcrop area of this unit was mapped in the northeast part of the Black Forest quadrangle capping Table Rock (sec 4, T. 11 S., R. 65 W.) and holding up the hills immediately to the east of that point (Thorson, 2003). Rocks which appear to be the conglomerate of Larkspur Butte have been found in the Cherry Valley School quadrangle but have not yet been studied in detail.

AGE OF THE WALL MOUNTAIN TUFF AND CASTLE ROCK CONGLOMERATE

The ignimbrite eruption which deposited the Wall Mountain Tuff has been considered in the past to be an Oligocene event, for example see Trimble and Machette, 1979a. Recent radiometric dates on its eruption are about 36.7 mybp (million years before present; Mcintosh and others, 1992; Mcintosh and Chapin, 1994). However, the age for the end of the Eocene is now recognized to be 33.7 mybp (Remane and others, 2002), so the Wall Mountain Tuff should now be considered to be late Eocene. The Castle Rock Conglomerate post-dates the Wall Mountain Tuff, even though it may outcrop at a lower elevation as on Best Butte (sec. 28, T. 10 S., R. 66 W.), since the conglomerate contains clasts of the tuff (Fig. 5). The Castle Rock Conglomerate also contains bones of Chadronain (late Eocene) titanotheres (K. R. Johnson, written commun., 2002) and so must be late Eocene in age, between 36.7 and 33.7 mybp.

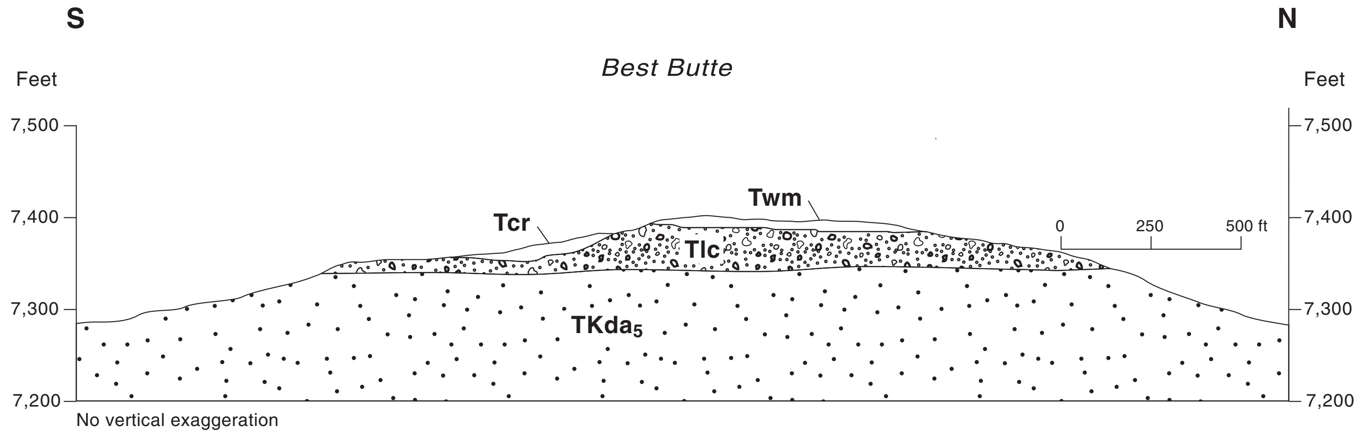


Figure 5. North-south sketch cross section of Best Butte showing the relationship between the Dawson Formation (TKda$_5$), the conglomerate of Larkspur Butte (Tlc), Wall Mountain Tuff (Twm), and Castle Rock Conglomerate (Tcr). The contact between the Dawson and conglomerate of Larkspur Butte is an erosional unconformity although the relationship can not be seen here. The Wall Mountain Tuff was deposited on top of the conglomerate of Larkspur Butte on a surface that dips to the northeast at about 100 feet per mile. The remnant of Castle Rock Conglomerate was deposited in a paleochannel that cut across the Wall Mountain Tuff and most of the conglomerate of Larkspur Butte.

DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSITS

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

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

ALLUVIAL DEPOSITS—Sand, silt, gravel, and clay transported and deposited by flowing water in channels or as unconfined runoff. The alluvial deposits in the Greenland quadrangle are predominantly composed of quartz, feldspar, and granite fragments derived mostly from arkosic source materials in the Dawson Formation. Most of the fragments in the channel and flood-plain (Qa and Qau), and terrace (Qt_1, Qt_2, Qt_3) deposits are subround coarse pebbles (less than 1.25 in.) or smaller grains. Occasional larger pebbles and small cobbles (up to about 4 in.) of well-rounded light-colored quartz and subangular to subround yellow-brown chert, and rare larger cobbles and small boulders of round to subround dark-pink to light-red Pikes Peak Granite are found in the channel, flood-plain, and terrace deposits. These exotic clasts cannot have been derived from the Dawson Formation but appear to be recycled from either the older surficial deposits, the conglomerate of Larkspur Butte, or from the Castle Rock Conglomerate. Large cobbles and small boulders of subround Dawson arkose or angular to subangular brownish-gray welded tuff in the alluvial deposits were derived from local sources.

A large part of the Greenland quadrangle is mantled by older alluvial deposits of probable Pleistocene age (Qp_1, Qp_2, Qp_3, Qp_4, Qpo_1, and Qpo_2). In many places the upper surface of these older alluvial deposits is preserved as a gently sloping planar surface from which the original base level for the deposit can be interpreted. The relative age of these deposits has been interpreted from the slope, base level, and position in the landscape. These deposits have been grouped together as "older alluvium" since they represent either higher elevations of the present drainage system (Qp_1, and perhaps Qp_2, Qpo_1, and Qpo_2) or deposits which can be related to an older drainage system (Qp_3 and Qp_4). In either case their form is being modified by erosion over wide areas.

The youngest of these older alluvial deposits, Qp_1, has surfaces which mimic the present drainage system. In the western part of the quadrangle these deposits slope towards Carpenter Creek, a tributary of Plum Creek. In the eastern part of the quadrangle, the deposits of Qp_1 slope toward West Cherry Creek, or its tributaries. The rest of the older alluvial deposits (Qp_2, Qp_3, and Qp_4) do not fully reflect the present drainage system and appear to pre-date significant headward erosion and stream capture by Carpenter Creek (Fig 6). Unit Qp_2 is composed of pink granite gravel and cobbles which clearly came from the granite terrane west of Palmer Lake, since these gravels form a paleochannel that caps the ridge in sec. 27, T. 10 S., R. 67 W. and can be followed up the ridge to NE1/4 sec. 4, T. 11 S., R. 67 W. in the Palmer Lake quadrangle. Remnants of this paleochannel have been traced northeastward, across the Carpenter Creek drainage, into sec. 18, T. 10. S., R. 66 W. very near the drainage divide at the head of Haskel Creek. This relationship suggests that the stream that flowed in the Qp_2 paleochannel drained out through what is now Haskel Creek before its capture by Carpenter Creek. The position of the oldest alluvial deposits, Qp_3 and Qp_4, at higher elevation positions in the landscape than Qp_2, suggests that these deposits may be the remnants of older drainage systems which flowed northeastward down Upper Lake Gulch.

Qa

Channel and flood-plain alluvium (late Holocene)—Pale-brown to brown sand, gravel, silt, and minor clay underlying narrow flood plains, stream channels, and locally, low terraces flanking flood plains. Unit is generally coarser, lighter in color, and more poorly sorted than unit 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 upper surface of the unit is 5-25 ft higher than some of the larger streams 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 Pleistocene)—Very pale-brown to light grayish-brown, extremely poorly sorted sand and subordinate amounts of gravel. The unit may correspond to the Kettle Creek Alluvium of Varnes and Scott (1967). The upper surface of the unit is typically 10–20 ft higher than the larger streams. Thickness is 5–20 ft.

Qt_3

Terrace alluvium three (late Pleistocene)—Chiefly pale-brown to light-grayish-brown, extremely poorly sorted sand and gravel that underlies terrace remnants along the larger streams of the area. The upper surface of the unit is 20–40 ft higher than Carpenter Creek and West Cherry Creek. Estimated thickness is 5–30 ft.

Qau

Alluvium, undivided (Holocene and Pleistocene)—Chiefly pale-brown to brown, poorly sorted sand and fine gravel in valley heads in the upper parts of drainages. The unit includes sheetwash and stream-deposited alluvium that are undivided. Reasons for not differentiating these deposits include 1) different ages of alluvium may be superposed but incision has not differentiated them, 2) exposures are poor, and 3) two or more units are present but are too small to show separately at the map scale. These alluvium-filled valley heads are not exhumed or deeply incised. The unit probably includes sediment that is correlative with units Qa, Qt_1, and possible Qt_2. Estimated thickness is 3–10 ft.

Qsq

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

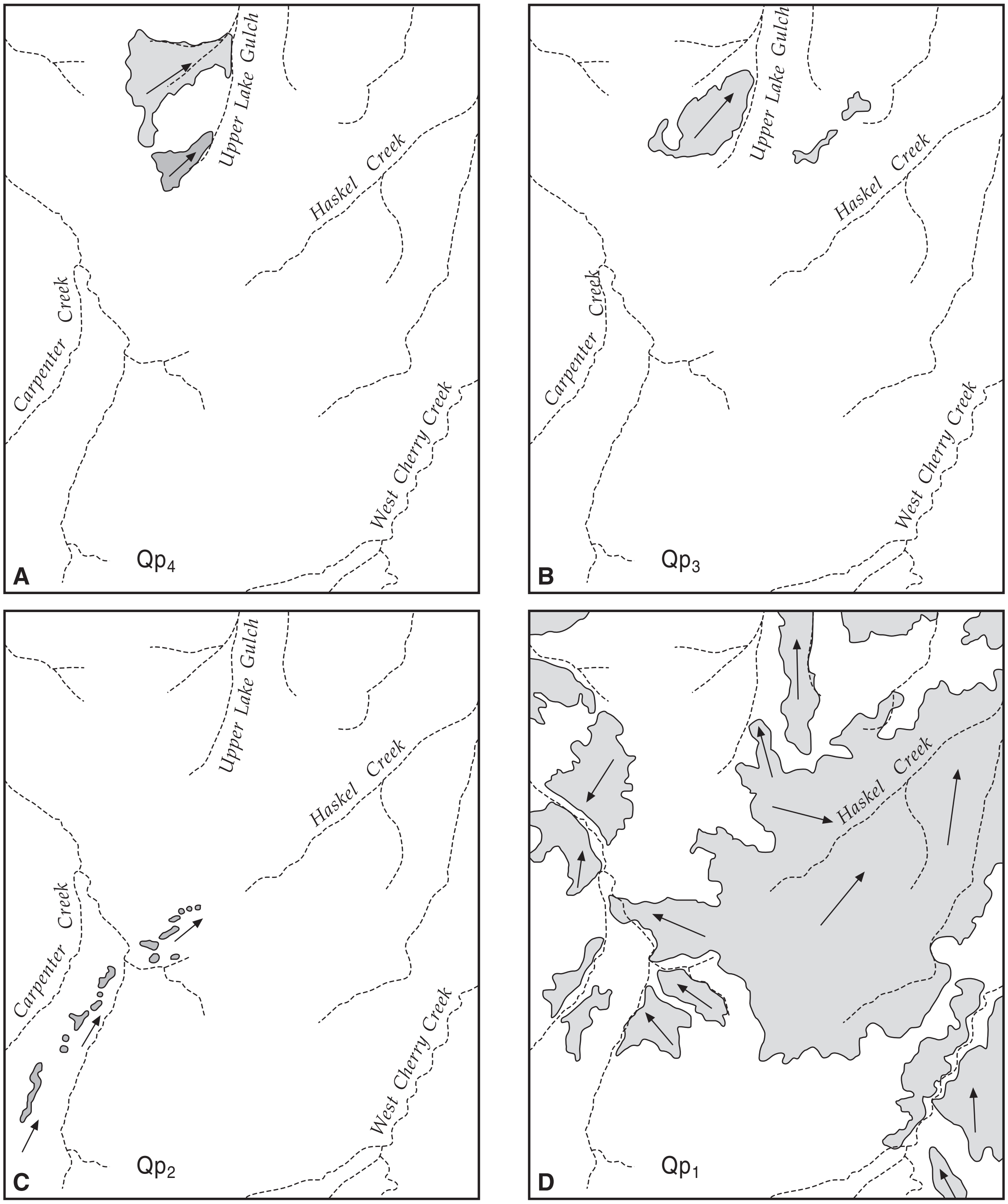


Figure 6. Paleo-streamflow directions (arrows) for deposits of Pleistocene older alluvium in the Greenland quadrangle. The directions of paleo-streamflow are interpreted from the slope of depositional surfaces or from the slope of deposits. Note for Qp_1—streamflow directions are toward streams of the existing drainage system (D). Qp_2 deposits are a paleochannel that crossed the present drainage of the tributary of Carpenter Creek at about 80 ft higher elevation, and may have drained through Haskel Creek (C). Qp_3 and Qp_4 deposits are only preserved east of the drainage divide between Carpenter Creek and Upper Lake Gulch and are 60 to 100 ft higher in the landscape than the deposits of Qp_2, suggesting the Qp_3 and Qp_4 represent even older paleo-drainage channels (A,B). Headward erosion of the Carpenter Creek–Plum Creek drainage has beheaded the Qp_3 and Qp_4 paleochannel deposits, and captured the Qp_2 drainage, probably in the Pleistocene. Continued erosion in the Holocene has incised the present drainage system to a lower level than the Qp_1 deposits.

Formation or from redistribution of colluvium (Qc), but a smaller amount may have been derived from the older alluvial deposits. Estimated thickness is 3-20 ft.

Qaf

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

Qp_1

Older alluvium one (late Pleistocene)— Chiefly light-brown to reddish-brown, extremely poorly sorted sand and coarse gravel, which, in places, includes boulders as well as pebbles and cobbles. The unit may have cobbly and bouldery layers with angular to sub-round fragments of Wall Mountain Tuff up to 12 in. and subrounded clasts of Dawson Formation arkose up to 2 ft in size. It is unusual to find clasts of either conglomerate of Larkspur Butte or pink to red Pikes Peak Granite in this unit. Two sub-units of this deposit (Qp_{1b} and Qp_{1s}) were mapped separately, where present. Some of older alluvium Qp_1 was mapped by Trimble and Machette (1979a) as Slocum Alluvium, to which it may be equivalent, but they greatly underestimated the distribution of this unit. At least 60 ft of Qp_1 is exposed in places; estimated thickness may be as great as 80 ft.

Older alluvium one grades into clayey sand deposits (Qp_{1s}) of light-brown, light- to medium-reddish-brown, or orange-brown, medium to very coarse sand. Sand grains are mostly subangular to subround quartz. These sand deposits are thin bedded and clearly stratified by alluvial processes; the darker colored layers have higher clay content. The deposit of Qp_{1s} in sec. 5, 7, and 8, T. 10 S., R. 66 W. was mapped by Trimble and Machette (1979a) as eolian. It is being modified by wind processes at the surface, but shallow pits dug in this deposit reveal that it is an alluvial deposit. Older alluvium one contains some poorly exposed, but coarser, bouldery deposits mapped as Qp1b. These deposits grade into Qp_1, but contain large boulders of Dawson Formation arkose up to 10 ft in size.

The slope of the Qp_1 older alluvium deposits, and of the upper surface where preserved, indicates that this is the youngest of the older alluvial deposits. Gently sloping surfaces that appear to be the original depositional surface can be seen in many areas. North of Larkspur Butte, in SW 1/4 sec. 26 and SE1/4 sec. 27, T. 9 S., R. 67 W., a smooth planar surface slopes westward toward East Plum Creek, located just west of the quadrangle boundary. Along Carpenter Creek, planar surfaces which appear to be depositional surfaces, slope gently toward that drainage. Good examples of these surfaces are located between Larkspur Butte and Rattlesnake Butte, and between Rattlesnake Butte and True Mountain. The slope of these surfaces, toward a drainage in approximately the same position as the present drainage but representing a higher base level, acknowledges the presence of an older drainage system that resembled the present drainage system (Fig. 6). The older alluvial deposits that are older than Qp_1 indicate drainages that have less similarities to the present system.

Qp_2

Older alluvium 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, but cobbles of white quartz are prominent. Older alluvium two is a distinctive unit among all of the alluvium in the quadrangle as it has darker reddish colors and a higher proportion of Pikes Peak Granite than the other alluvial units. Clasts of Dawson Formation arkose and Wall Mountain Tuff are conspicuously absent. Some of the outcrops of this alluvium were mapped as Verdos Alluvium by Trimble and Machette (1979a). It resembles other deposits mapped as Verdos by them and by Scott and Wobus (1973) in the Pikeview and Monument quadrangles, but the correlation of these deposits with the Verdos of the Denver area remains unconfirmed. Similar but less distinctive deposits (Qpo_2), on the west side of Carpenter Creek, were also mapped as Verdos by Trimble and Machette (1979a). Estimated thickness is 5–50 ft.

The unit caps ridges and knolls in the southwestern part of the quadrangle along a line of outcrops which may be an inverted paleodrainage. In sec. 13 and 24, T. 10 S., R. 67 W. the gravel-capped hills that are remnants of this paleodrainage extend northeastward across a tributary of Carpenter Creek. The base of this Qp_2 paleodrainage is about 80 ft above the tributary of Carpenter Creek, and high enough in elevation that the paleodrainage might have extended further northeast, down the present northeast alignment of Haskel Creek (Fig. 6). Clearly this paleodrainage is older than the present drainage system, and possibly represents the youngest part of an older drainage system that was captured by the headward erosion of the Carpenter Creek–Plum Creek drainage. Similar stream capture can be postulated for older alluvium deposits Qp_3 and Qp_4. In the Monument quadrangle, similar stream capture was postulated by the headward erosion of Monument Creek (Thorson and Madole, 2002).

Qp_3 **Older alluvium three (middle? Pleistocene)—**Unit is similar to unit Qp_4 but less well exposed. It occurs as two deposits that slope gently toward Upper Lake Gulch in the northern part of the quadrangle, essentially parallel in slope to Qp_4, but about 50 ft lower in elevation. This unit appears to be either a modification of the Qp_4 deposit or a later deposit. Its upper edge is eroded away at the north-south drainage divide in sec. 25 and 36, T. 9 S., R. 67 W. (north of Corner Mountain) as is Qp_4. The upper surfaces of Qp_1 and Qp_2 are clearly lower than this deposit, so the unit is probably older than them and younger than Qp_4. Thickness may be 20 to 40 ft.

Qp_4 **Older alluvium four (early? Pleistocene)—**This deposit is composed of light-brown sand and fine gravel that appears to be derived from the Dawson Formation, plus cobbles and small boulders of Dawson Formation arkose up to 2 ft, cobbles of Wall Mountain Tuff up to about 8 in., and lesser amounts of well-rounded cobbles of white quartz and pink or reddish-brown Pikes Peak Granite up to 8 in. in diameter. Unit is about 45 to 60 ft thick.

Qp_4 is the highest alluvial deposit in the Greenland quadrangle and, therefore, probably the oldest. The high end of the large deposit just north of Corner Mountain and the two smaller deposits on the drainage divide to the northeast of Corner Mountain are located at elevations near 7,200 ft. On the drainage divide between a tributary to East Plum Creek and Upper Lake Gulch (just north of Corner Mountain), the upper end of this deposit has clearly been eroded, and the adjacent upper end of the Qp_1 deposit is about 100 ft lower in elevation. Qp_4 slopes towards the northeast. Its truncated upper end, high elevation, and granite clast content suggests that this deposit is also (like Qp_3) the beheaded end of a paleovalley that pre-dates the development of the East Plum Creek drainage (Fig. 6). This paleovalley may have been tributary to an older alignment of Upper Lake Gulch which was beheaded by stream capture. Similar stream capture alterations of paleodrainages is suggested by the alignment of Qp_2 outcrops with Haskel Creek, and by older stream deposits in the Monument quadrangle (QTa) that pre-date the development of Monument Creek (Thorson and Madole, 2002).

Trimble and Machette (1979a) included the largest Qp_4 deposit on their map and designated it as Rocky Flats Alluvium. However, Qp_4 does not resemble the Rocky Flats Alluvium they mapped in sec. 17, T.10 S., R. 67 W. in the Larkspur quadrangle. There, the Rocky Flats Alluvium is composed predominantly of subround pebbles and cobbles of pink to reddish-brown Pikes Peak Granite with a few well-rounded clasts of white quartz. That deposit caps a ridge below 7,100 ft in elevation and slopes toward East Plum Creek. Thus, Qp_4, which is located at a higher elevation and has a different composition, is probably older than the Rocky Flats Alluvium. The correlation of both the Rocky Flats Alluvium in the Larkspur quadrangle and the Qp_4 deposits in the Greenland quadrangle to the Rocky Flats Alluvium of the Denver area remains unconfirmed.

Qpo_1 **Older alluvium one, undifferentiated (Pleistocene)—**This unit is composed of light-brown extremely poorly sorted sand and coarse gravel, which includes boulder beds as well as pebbles and cobbles. The coarser material includes both large boulders of Dawson Formation arkose (up to 4 ft) and cobbles of white quartz and pink or reddish-brown Pikes Peak Granite. This composition makes it similar to the unit Qp_1 boulder deposits (Qp_{1b}) but those only rarely contain granite clasts. It is similar to unit Qp_2, but that deposit usually does not contain the high proportion of Dawson Formation arkose boulders. Therefore it was mapped separately in two exposures in the east-central part of the quadrangle. This deposit could be another boulder bed in Qp_1 with a high proportion of granite and quartz cobbles derived from the conglomerate of Larkspur Butte strata in the buttes to the south of its outcrop area. Or, it could also be an old stream channel deposit of Qp_2 age developed when the Qp_2 paleodrainage was a through-going stream along Haskel Creek. The Qpo_1 deposit is lower in elevation than Qp_3 and Qp_4 so is probably younger than those deposits. Estimated to be 20 to 30 ft thick.

Qpo_2 **Older alluvium two, undifferentiated (Pleistocene)—**This unit is similar to Qp_2 in that it is dominated by quartz and pink feldspar that appears to be derived from the Pikes Peak Granite; however, it is lighter in color, finer grained than Qp_2, and contains fewer clearly identifiable granite clasts. Like Qp_2, this unit was also mapped by Trimble and Machette (1979a) as Verdos Alluvium, a correlation which remains to be confirmed. Estimated to be 40 to 60 ft thick.

MASS-WASTING DEPOSITS—Earth materials that were moved downslope 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 is the principal product of mass wasting in the Greenland 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 includes minor amounts of sheetwash alluvium and minor deposits from debris flows and deposits from these processes that are too small, or too indistinct, to map separately.

Qc **Colluvium (Holocene and late Pleistocene)—**Unit comprises slope deposits that consist of light-brownish-gray, very pale-brown, to brown sand and fine gravel plus arkose cobbles and boulders of Dawson Formation, pink and brown conglomerate of Larkspur Butte, and brown, brownish-gray, and lavender-gray clasts of Wall Mountain Tuff. The colluvium deposits typically are massive and very poorly sorted to extremely poorly sorted. It appears to grade laterally into deposits of late Pleistocene alluvium (Qp_1), alluvial fans (Qaf), and sheetwash (Qsw), as the slopes become more gentle and the transport mechanism becomes dominated by water flow rather than gravity. Unit is estimated to be 5–20 ft thick.

This material has consistent size distribution and rounding patterns. The finer material is sand and fine pebbles that make a gruss-like deposit that appears to be derived from disintegration of Dawson Formation arkose. The fine material probably contains some quartz and feldspar derived from the conglomerate of Larkspur Butte, but pink feldspar from that source is relatively rare in the finer part of the colluvium so its contribution must be subordinate. Similarly, small pebble-size clasts of Wall Mountain Tuff are uncommon. Recognizable arkose cobbles and boulders of the Dawson Formation, generally in the size range from 6 in. to 3 ft and well rounded, are relatively uncommon. The conglomerate of Larkspur Butte dominates the fragments in the boulder size classification, and these are very irregular in shape and may be huge, up to 45 ft in largest dimension. The Wall Mountain Tuff fragments in the colluvium are predominantly in the size range from 4 to 18 in. and angular in shape.

These size and shape distributions illustrate the relative strength of materials of the three source rocks for the colluvium. The Dawson Formation arkose is clayey and relatively friable, and disintegrates to make the finer grained matrix material of the colluvium. The Dawson less commonly weathers to boulders. The well-cemented conglomerate of Larkspur Butte forms cliffs, which are undermined by weathering of the Dawson Formation, and collapse as large boulders. The Wall Mountain Tuff fractures on its outcrops to angular platy fragments that fall over the cliffs with little significant rounding or further reduction in size as they are transported in the colluvium.

Colluvium generally accumulates on or near the base of slopes around the buttes capped by the conglomerate of Larkspur Butte and Wall Mountain Tuff. Notable exceptions are the circular clusters of small hills in SE 1/4 sec. 34, T. 9 S., R. 67 W. (just southwest of Larkspur Butte) and SW 1/4 sec. 1, T. 10 S., R. 67 W. (just southwest of Corner Mountain). Careful examination of the colluvium covering these hills reveals that the colluvium is thin and that there are many small exposures of the underlying Dawson Formation facies unit five ($TKda_5$), most of which are too small to show at the map scale. Also apparent in these hills is the presence of boulders of conglomerate of Larkspur Butte and cobbles and boulders of Wall Mountain Tuff that are just as as abundant as in the colluvium which flanks buttes capped by those lithologies. Therefore, it seems reasonable to conclude that these clusters of colluvium-covered hills are the remnants of now-eroded buttes that previously had conglomerate and tuff caprocks.

EOLIAN DEPOSITS—Wind-deposited sediment.

Qes

Eolian sand (middle and late Holocene)— Very pale-brown, pale-brown, and light-grayish-brown sand. Unit is predominantly fine- to medium-grained sand that appears to have been blown out of the East Plum Creek drainage and deposited on top of the Qp_1 alluvial unit. Thickness is estimated to be 3–15 ft.

BEDROCK DEPOSITS

Tcr

Castle Rock Conglomerate (late Eocene)— The Castle Rock Conglomerate is a pebble, cobble, and boulder arkosic conglomerate composed predominantly of subround to round fragments of pink and gray granite and quartz with subordinate amounts of gneissic metamorphic rocks, quartzite, red sandstone, and chert. The distinguishing characteristic of this unit is the presence of angular to subangular cobble to boulder-size clasts of gray, brownish-gray, maroon, or lavender-gray welded tuff which have been eroded from deposits of the Wall Mountain Tuff. The Castle Rock Conglomerate was deposited on an erosion surface cut across the top of the upper Dawson Formation, conglomerate of Larkspur Butte, and Wall Mountain Tuff (Fig. 5). In places the Castle Rock Conglomerate has been reported to overly the Wall Mountain Tuff (Morse, 1979, 1985), but this relationship was not observed in the Greenland quadrangle. The Castle Rock Conglomerate is younger than the Wall Mountain Tuff, which has been dated at about 36.7 my (Mcintosh and others, 1992; Mcintosh and Chapin,1994). It must be older than the end of the Eocene (33.7 my; Remane and others, 2002) since it contains bones of titanotheres (late Eocene, K. R. Johnson, written commun. 2002).

Twm

Wall Mountain Tuff (late Eocene)—The Wall Mountain Tuff is a moderately to densely welded tuff of rhyolitic composition (Izett and others, 1969; Epis and Chapin, 1974). It is generally light- to medium-brown when fresh but is occasionally medium-gray in a few of the more densely welded outcrops. On weathering it may be light-brown, lavender, pink , reddish-brown, or maroon. The fine-grained groundmass usually contains small phenocrysts of biotite and sanidine, and occasionally near the base may contain quartz grains and small arkose fragments ripped up from the underlying strata. Small float fragments of yellowish-green clayey devitrified tuff were found occasionally near the base of the welded tuff unit, but this material was not found in an exposure. The Wall Mountain Tuff was emplaced in the Greenland quadrangle as an ash-flow that was hot enough that the ash compacted and welded into viscous plastic after emplacement. In places the welded ash flowed and developed flow-banding before cooling and solidifying. The Wall Mountain Tuff has been dated as about 36.7 million years in age by McIntosh and others, 1992; (McIntosh and Chapin, 1994). The ash was erupted from the Thirtynine Mile volcanic field (Epis and Chapin, 1974).

In the Greenland quadrangle the Wall Mountain Tuff is about 5 to 50 ft thick. It caps many of the higher buttes in the quadrangle as a flat or very gently sloping deposit resting either on the conglomerate of Larkspur Butte or on the Dawson Formation. The surface on which the welded tuff was deposited now slopes gently towards the northeast on a gradient of about 100 ft per mi.

On most outcrops the welded tuff is fractured horizontally into hackly plates generally about 4 to 8 in. thick. Most of the outcrops of Wall Mountain Tuff in the Greenland quadrangle have been tested long ago for their potential as building stone quarries. Small overgrown test pits are common on welded tuff outcrops but the testing results were apparently considered negative since little quarrying was done. One small quarry was found on the south side of Lincoln Mountain.

Tlc

Conglomerate of Larkspur Butte (late? Eocene)—The conglomerate of Larkspur Butte is a brown, pinkish-brown, or pink arkosic conglomerate predominantly composed of pebbles and cobbles of pink granite or pink feldspar in a coarse sand-size to small-pebble matrix composed of quartz and pink feldspar. Clasts of gray or white quartz are common; clasts of gneissic metamorphic rocks, quartzite, red sandstone, and chert are less common. Clasts are subround to round. Large clasts of arkose of the eroded Dawson Formation are common near the base of the unit. Minor interbeds of coarse to very coarse light-brown sandstone occur locally. The unit is strongly cross bedded in large sets that indicate deposition in channels 5 to 15 ft deep. The conglomerate of Larkspur Butte rests on an erosional unconformity on the top of the Dawson Formation. The unconformity has up to 50 to 60 ft of relief where well exposed on Larkspur Butte. Similar channel-edge geometry relationships can be seen on Corner Mountain, Rattlesnake Butte, True Mountain, and Bald Mountain.

On Larkspur Butte in the northwest corner of the Greenland quadrangle the unit contains granite clasts up to 8 in. in diameter, but clast size decreases regularly towards the southeast. Although there are only remnants left, the unit appears to thicken towards the southeast; on Best Butte, and the hills nearby, the conglomerate may be as thick as 120 ft. In the northeast part of the Black Forest quadrangle, about 15 mi southeast of Larkspur Butte, the largest clasts are cobbles about 3 in. in the largest dimension. In the northeast part of the Black Forest quadrangle this unit appears to fill a broad channel with at least 80 ft of erosional relief on the top of the Dawson Formation (Thorson, 2003).

The conglomerate of Larkspur Butte is distinguished from the underlying Dawson Formation by its coarser grain size, pinkish color tones, predominance of pink granite and unbleached pink feldspar grains, and lack of clay in the matrix material. The conglomerate of Larkspur Butte is remarkably free of clay filling in the matrix porosity.

The conglomerate of Larkspur Butte is similar in appearance to the Castle Rock Conglomerate although the latter generally lacks pink tones and is light gray in color. The principal distinguishing characteristic is the fragments of Wall Mountain Tuff in the Castle Rock Conglomerate. In the absence of tuff fragments, the two late-Eocene conglomerates may be very hard to distinguish.

Dawson Formation (Upper Cretaceous to Eocene)—The Dawson Formation is divided into upper and lower parts in the Colorado Springs area (Fig. 3). The lower part is entirely Upper Cretaceous in age and composed almost exclusively of andesitic debris, but it is not exposed in the Greenland quadrangle. The lower part of the Dawson may be present in two abandoned petroleum test wells in the Greenland area (F.G. Holl et al., #1 Greenland Land & Cattle Co., SE 1/4 N1/4 sec. 17, T. 10 S. , R. 66 W.; and Petro-39, 1 Higby, SW 1/4 SW 1/4 sec. 27, T. 10 S., R. 67 W.), but the the logs and cuttings are poor and not conclusive.

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.

Mapping in the Greenland, and adjacent Monument and Black Forest quadrangles (Thorson and Madole, 2002; Thorson, 2003), indicates that only the uppermost facies unit ($TKda_5$) occurs in the Greenland quadrangle and that some of the uppermost part has been removed by erosion. Logs and samples from the Dawson in the abandoned petroleum test well (sec 17, T. 10 S., R. 66 W. (F.G. Holl et al., No. 1 Greenland Cattle Co.), plus the thickness of Dawson exposed on the adjacent buttes above the collar of the well, indicate that the Dawson Formation is about 2,750 ft thick in the Greenland quadrangle.

$TKda_5$ **Facies unit five (early to middle? Eocene)—** The $TKda_5$ unit is dominated by very thick-bedded to massive, cross-bedded, light-colored arkoses, pebbly arkoses, and arkosic pebble conglomerate, but also contains common beds of white to light-tan, fine- to medium-grained feldspathic, cross-bedded friable sandstone. These sandstones are poorly sorted, have high clay contents, and are often thin or medium bedded; wavy bedding and ripple cross-laminations are common in the finer-grained parts. Facies unit five also contains massive structureless beds interpreted to be mudflows. The uppermost strata of the Dawson are generally very light colored (white, cream, light greenish gray) because most of the feldspar in the Dawson Formation arkose is bleached and essentially all of the macroscopic porosity of the Dawson beds is filled with light colored clay. The bleaching and clay-filling in the Dawson suggests a prolonged period of weathering and/or diagenetic alteration of the Dawson before deposition of the conglomerate of Larkspur Butte.

Throughout the Greenland quadrangle, $TKda_5$ contains thin, poorly developed, red, pink, and yellow-brown oxidized zones interbedded with, or developed within, the thick arkoses. Some of these oxidized zones have preserved mottling, burrows, and root structures which indicate their origin as paleosols; others are probably just the result of oxidation by groundwater. $TKda_5$ is at least 800 ft thick in the quadrangle; the base is not exposed and the top of the unit has been removed by erosion.

$TKda_5$ is generally permeable, well drained, and has good foundation characteristics. Excavation may be difficult, even though the arkoses are friable and easily eroded on weathered outcrops. The massive mudflow beds can be well indurated and may require considerable effort to excavate. The clay content of the finer grained parts of the facies unit suggest that soils developed from the Dawson may have high swell factors. Facies unit five appears to be equivalent to the Dawson Arkose and/or Dawson aquifer in the Denver area (George VanSlyke, 2001, oral commun.).

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

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

Kf **Fox Hills Sandstone (Upper Cretaceous)—** Greenish-gray to yellowish-brown micaceous sandstone. About 300 ft thick; shown only on cross section A–A'.

Kp **Pierre Shale (Upper Cretaceous)—**Predominantly gray to dark-gray shale. About 5,000 ft thick; shown only on cross section A–A'.

Ku **Older Cretaceous, undivided (lowermost Upper Cretaceous and Lower Cretaceous)—**Niobrara Formation, Carlile Shale, and Greenhorn Limestone, shown only on cross section A–A'.

Kd **Dakota Group, undivided (Lower Cretaceous)—**Sandstone and shale including the Dakota, Skull Creek and Lakota Formations; shown only on cross section A–A'.

Jm **Morrison Formation (Jurassic)—**Variegated shales and sandstones; shown only on cross section A–A'.

STRUCTURAL GEOLOGY

The structural geology of the Greenland quadrangle is not complex. Bedrock units dip gently to the northeast at 2° to 6° across most of the quadrangle. Strike and dip symbols are not abundant on the map because of poor outcrop exposures. Measurement of strike and dip in the Dawson Formation is difficult and questionable because of the coarse-grained, lenticular, and cross-bedded character of most of the beds. Bedding surfaces and cross-bed orientation from these beds were inclined at deposition and are unlikely to be representative of the strike and dip of the whole unit. Strike and dip measurements shown on the map were made on thin-bedded, fine-grained strata that were more likely deposited in a horizontal orientation.

On cross section A–A', a gentle syncline is shown near the eastern edge of the map area. The exact location of this structural flexure is only generally known since the cross section is constrained only by three oil wells: F.G. Holl et al., #1 Greenland Land & Cattle Co. (SE 1/4 N /4 sec. 17, T. 10 S. , R. 66 W.); Petro-39, 1 Higby (SW 1/4 SW 1/4 sec. 27, T. 10 S., R. 67 W.); and National Associated Petroleum, #1 State (SE 1/4 SE 1/4 sec. 36, T. 9 S., R. 66 W.). The location of the Holl well is shown on the map. The Petro-39 well is located about 2,600 ft west of the edge of the quadrangle along the southwest projection of section line A–A'. The National Associated Petroleum well is located about 8,700 ft east of the quadrangle on the northeast projection of section line A–A'. The synclinal flexure is the axis of the Denver Basin. Its location on the cross section A–A' is approximately coincident with that drawn by other authors, for example, see Robson (1987, 1989).

Cross section B–B' shows the regional dip of the Wall Mountain Tuff through a number of the buttes on which the unit outcrops. A three-point solution for the strike and dip of the surface on which the Wall Mountain Tuff was deposited, using the elevation of the base of the unit on Larkspur Butte, Bald Mountain, and Lincoln Mountain, yields a strike of N45°W with a dip of about 100 ft per mi toward the northeast. Section B–B' shows that surface in approximately true dip.

MINERAL RESOURCES

Sand, gravel, and stone are the most significant potential mineral resources in the Greenland quadrangle. Test wells for oil and gas reported no shows and were abandoned. No metallic or radioactive mineral resources are known in the quadrangle.

SAND AND GRAVEL

Sand and gravel are widely available in the quadrangle from surficial deposits derived mostly by erosion of the Dawson Formation, but there is little indication that these resources are currently being exploited from the quadrangle. Locations for two sand pits are shown in the eolian sand deposit in the northwest corner of the quadrangle (NE 1/4 sec. 27, T. 9 S., R. 67 W.) but these workings have apparently been filled and reclaimed; considerable amounts of this resource remains. Two additional abandoned gravel pits are shown by Schwochow and others (1974) in SW 1/4 sec. 3, T. 10 S., R. 66 W. and NW 1/4 sec. 2, T. 11 S., R. 67 W. Additional data on sand and gravel resources in the Greenland quadrangle are available in Trimble and Fitch (1974).

Well-sorted, medium- to coarse-grained sand is available from the deposit labeled Qp_{1s} adjacent to Upper Lake Gulch Road in sec. 26, T. 9 S., R. 67 W., and adjacent to the Greenland Road in sec. 8, T. 10 S., R. 66 W. High-quality gravel composed of quartz and feldspar derived from the Pikes Peak Granite could be available from the deposits labeled Qp_2 and Qpo_2 along the southwestern edge of the map area, sec. 10, 15, and 27, T. 10 S., R. 67 W.

BUILDING STONE

The Wall Mountain Tuff has been extensively quarried for building stone in the Castle Rock area for over a century. Most of the outcrops of this unit in the Greenland quadrangle have been tested as potential quarry sites. These locations were apparently reached by foot or pack trails and abandoned after small pits were excavated. A small quarry, about 30 by 50 ft in area, on the south side of Lincoln Mountain had road access and may have had minor production. The erosional remnants of Wall Mountain Tuff in the Greenland quadrangle are small and in relatively inaccessible locations but have been suggested as sources for crushed aggregate by Schwochow and others (1974) and Trimble and Fitch (1974).

OIL AND GAS

The Colorado Oil and Gas Commission has completion records for four petroleum test wells drilled in or near the Greenland quadrangle. All four of these wells were unsuccessful and abandoned. The nearest oil production is about 30 mi northeast of the Greenland quadrangle, north of Kiowa in Elbert County.

In 1952, National Associated Petroleum drilled the #1 State well from a location in SE 1/4 NE 1/4 sec. 36, T. 9 S., R. 66 W. about 8,700 ft east of the quadrangle along the projection of cross section A–A'. This well tested the Lower Cretaceous Dakota Group sandstone beds and terminated at 9,670 ft in the Jurassic Morrison Formation.

In 1955, F.G. Holl and others drilled the #1 Greenland Land & Cattle Co. well in SE 1/4 NE 1/4 sec. 17, T. 10 S., R. 66 W and tested both the Laramie Formation and Dakota Group sandstone beds. The Holl well also terminated in the Morrison Formation, at 9,847 ft.

In 1970, Trans-State Oil, Ltd. tested a location (just west of the southwestern part of the Greenland quadrangle) in NW 1/4 NW 1/4 sec. 34, T. 10 S., R. 67 W. with the #1 Higby well which was abandoned at 3465 ft in the Upper Cretaceous Pierre Shale. This area was again tested in 1981 by Petro-39 with another #1 Higby well. The new location was in SW 1/4 SW 1/4 sec. 27, T. 10 S., R. 67 W., just west of the quadrangle about 2600 ft along the projection of cross section line A–A'. Petro-39's #1 Higby well tested the Dakota Group where it was terminated at 9,554 ft.

GEOLOGIC HAZARDS
By John W. Himmelreich, Jr.

Several geologic processes may effect planning and ultimate development within those portions of the Greenland quadrangle likely to be developed, especially near the buttes and in the steeper slope areas. Special attention will be needed during planning and development because of mass movement, slope stability, and seismic risk potential.

DEBRIS FLOWS (ROCKFALL, ROCK AVALANCHE, DEBRIS AVALANCHE)

The buttes and mesas have been subjected to various mass-wasting phenomena over the recent geologic past. These include debris flows, rockfall, debris avalanche, and rock avalanche where masses of locally derived debris were moved down slope by gravity and/or water (here-in called debris flows). Debris flows in the region are known to have affected areas several hundred ft beyond the base of the steeper slopes. Significant risk is involved in developing areas near the buttes for residential housing or other permanent structures. Detailed analysis of the steeper slopes where construction is planned and design of roadways on the steeper slopes should evaluate these risks as part of final planning. On the geologic map the deposits of debris flows are included in the map units colluvium (Qa), slopewash (Qsw), and alluvial fans (Qaf), since they are generally too small or too indistinct to map separately at this scale.

Debris-flow deposits, which consist of fans, lobes and tongues of unsorted debris, are created by the down-slope flow of rocks, soil, and vegetative matter often in a watery, muddy slurry typically triggered or generated by severe storms. Debris flows may build their own channels by gouging out material and depositing it as levees. Each butte has unique debris-flow hazards resulting from different conditions. Variables include: size of the tributary drainage basins; debris source, amount, and character; character and magnitude of the storm; slope gradient and height; roughness of the slope or channel, vegetation cover and other factors.

Debris-flow deposits formed by recent (May, 1973) and older debris flow activity have been recognized and reported within the quadrangle and in the region (Hanson, 1973; Soule, 1978). Himmelreich and Bowden (1993) mapped debris-flow deposits in portions of the Greenland quadrangle. Evaluation of debris flow hazards around Spruce and Eagle Mountains, located in the adjacent Larkspur quadrangle, indicates the region was also affected by debris-flows during June, 1965, storm events (Himmelreich, 2001). Other older debris-flow deposits, estimated to be greater than 200–300 years old, were also mapped along the base of Spruce Mountain by Himmelreich (2001). The east end of Spruce Mountain is located in sec. 22, T. 10 S., R. 67 W. on the Greenland quadrangle. Debris-flow hazards have also been mapped within the Greenland quadrangle by Soule (1978).

Several techniques are available for the mitigation of debris flows. These might include avoidance, debris basins (to be cleaned after each flow event), channelization and/or diversion, protective structures, debris catching devices, and/or elevated structures (Johnson and Himmelreich, 1998). Detailed analysis of debris-flow risk should take into account both current watershed conditions and the risk associated with potential adverse conditions, for example, deforestation of the watershed by fire (see Code of Federal Regulations 44CFR Part 65; Kirkham and others (2000); Rasely and Petersen, 1998; Hyde and Browning, 1998; and Himmelreich, 1991). The evaluation of potential risks should also include detailed geologic, geomorphic, topographic, and historical analysis of the watershed area to include the past 1,000 years (FEMA, 1999; Himmelreich 1981, 2001).

SLOPE STABILITY

Alterations of steep slopes and other factors can adversely affect the stability of slope conditions, especially on marginally stable (potentially unstable) slopes. Some risk is involved in developing these areas. Parts of the slope mass could be destabilized if support is removed, the materials become saturated, and/or the slope is loaded either naturally or by fill placement. The steeper slope areas should be considered as potentially unstable and can be subject to sliding or creep (slow down-slope movement of the upper few to several ft of soil). Without proper planning, design, and construction, development in these steep slope areas could result in the creation of slope instabilities.

SEISMICITY

The Rampart Range Fault, located about 3 mi west of the Greenland quadrangle is one of the major structural features of the region. Evidence for movement during the last two million years (Quaternary) exists for some Front Range faults including the Rampart Range Fault. The Rampart Range Fault is considered to be potentially active by the Colorado Geological Survey. Earthquakes have occurred along this fault in recent times and have been felt in the Castle Rock area (December 23 and 25, 1994; December 31, 1994) and other parts of the Front Range. Other earthquakes that appear to originate from movement along this fault, or the Ute Pass Fault, have been felt in Colorado Springs, Manitou Springs, Victor, and Cripple Creek (Matt Morgan, written commun., 2003). This area, like most of central Colorado, is subject to a degree of seismic risk. The Colorado Geological Survey considers this area of Colorado to be in Seismic Risk Zone 2 (Kirkham and Rogers, 1981). If a sizable seismic event did occur, it may trigger slope failures or rockfalls.

REFERENCES CITED

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

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

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

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

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

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

Farnham, T.M., 2001a, Lateral variability of hydromorphic paleosols spanning the Paleocene/Eocene boundary in the Denver Basin, Colorado: Denver Basin Project Spring Science Meeting, Denver, May 18, 2001, unpublished conference abstract.

Farnham, T.M., 2001b, Alluvial paleosols spanning the Paleocene-Eocene boundary in the Denver Basin; hydromorphic characteristics, temporal significance, and lateral variability: Boulder, Colo., University of Colorado, Master's thesis, 70 p.

Farnham, T.M., and Kraus, M.J., 2002, The stratigraphic and climatic significance of Paleogene alluvial paleosols in synorogenic strata of the Denver Basin, *in* Johnson, K.R., Raynolds, R.G., and Reynolds, M.L., eds., Paleontology and stratigraphy of Laramide strata in the Denver Basin: Rocky Mountain Geology (The Denver Basin Issue), v. 37 no. 2.

FEMA (Federal Emergency Management Agency), 1999; Guidelines for determining flood hazards on alluvial fans.

Fenneman, N.M., 1931, Physiography of western United States: New York, McGraw-Hill, 534 p.
Finlay, G.I., 1916, Colorado Springs folio, Colorado: U.S. Geological Survey Geologic Atlas Folio 203.
Hansen, W. R., 1973, Effects of the May 5-6, 1973, storm in the greater Denver area, Colorado: U. S. Geological Survey Circular 689, 20 p.
Hilgard, E.W., 1892, A report on the relations of soil to climate: U.S. Department of Agriculture, Weather Bureau Bulletin 3, 59 p.
Himmelreich, J. W., Jr., 1981, Debris flow hazard analysis, vicinity of Ski Broodmoor, The Broadmoor Property, Colorado Springs, Colorado: Lincoln DeVore, Inc., Job No. 37586.
Himmelreich, J. W., Jr., 1991, Interim report on geologic hazards study, Broadmoor South, Colorado Springs, CO: Geotechnical Consultants, Inc., Job No. 3865.
Himmelreich, J. W., Jr., 2001, Preliminary geologic hazards investigation, Spruce Mountain Ranch, Douglas County, Colorado: John Himmelreich & Associates Project No. 01-100, unpublished report.
Himmelreich, J. W., Jr., and Bowden, W. L., 1993, Reconnaissance engineering geology map, Greenland Ranch, Douglas County, Colorado: CTL/Thompson, Inc., Job No. CS-3508, unpublished report.
Hyde, B. R., and Browning, T. W., 1998, Hydrologic changes in a wildfire burn area; Buffalo Creek, Colorado; a continuing case study in Proceedings of the Conference on Geologic Hazards and Engineering Practices in Western Colorado, October 29 and 30, 1998: Colorado Geological Survey.
Izett, G.A., Scott, G.R., and Obradovich, J.D., 1969, Oligocene rhyolite in the Denver Basin, Colorado: U.S. Geological Survey Professional Paper 650-B, p. B12-B14.
Johnson, E.J., and Himmelreich, J. W., Jr., 1998, Geologic hazards avoidance or mitigation; A comprehensive guide to state statutes, land use issues, and professional practice in Colorado: Colorado Geological Survey Information Series 47.
Johnson, K.R., 2001, Fossil plants in the Denver Basin provide insight to climate, local habitat, extinction, and rainfall patterns related to uplift of the Front Range: Denver Basin Project Spring Science Meeting, Denver, May 18, 2001, unpublished conference abstract.
Johnson, K.R., and Raynolds, R.G., 1998, Field trip guide to the Upper Cretaceous and Lower Tertiary formations and fossil plants of the western Denver Basin: 15th Mid-continent Paleobotanical Colloquium, Denver, Colo., May 10, 1998, unpublished conference field guide.
Johnson, K.R., and Raynolds, R.G., 2001, Research on paleontological and geological resources of the Denver Basin near Colorado Springs with emphasis on the Jimmy Camp Creek and Corral Bluffs area: Denver Museum of Nature & Science, Denver, Colo., 2000 Colorado Natural History Small Grants Program, unpublished final report, 3 p.
Kirkham, R.M, Parise, M. and Cannon, S.H., 2000, Geology of the 1994 South Canyon fire area, and a geomorphic analysis of the September 1, 1994 debris flows, south flank of Storm King Mountain, Glenwood Springs, Colorado: Colorado Geological Survey Special Publication 46.
Kirkham, R.M., and Rogers, W.P, 1981, Earthquake potential in Colorado: Colorado Geological Survey, Bulletin 43.
Kluth, C.F., and Nelson, S.N., 1988, Age of the Dawson Arkose, southwestern Air Force Academy, Colorado, and implications for the uplift history of the Front Range: Mountain Geologist, v. 25, no. 1, p. 29-35.
Madole, R.F., 1991, Colorado Piedmont, *in* Wayne, W.J., ed., Quaternary geology of the Northern Great Plains, chapter 15 of Morrison, R. B., ed., Quaternary nonglacial geology--Conterminous United States: Geological Society of America, The Geology of North America, v. K-2, p. 444–445, 456-462.
Madole, R.F, 2003, Geologic map of the Falcon NW quadrangle, El Paso County, Colorado: Colorado Geological Survey Open-File Report 03-8, scale 1:24,000,
Madole, R.F., and Thorson, J.P., 2002, Geologic map of the Elsmere quadrangle, El Paso County, Colorado: Colorado Geological Survey Open-File Report 02-02, scale 1:24,000,
Mcintosh, W.C., and Chapin, C.E., 1994, 40Ar/39Ar geochronology of ignimbrites in the Thirtynine Mile volcanic field, Colorado, *in* Evanoff, E., ed., Late Palogene geology and paleoenvironments of central Colorado: Geological Society of America Field Trip Guidebook, p. 23-26.
Mcintosh, W.C., Swisher, C.C., and Chapin, C.E., 1992, Single-crystal laser-fusion $^{40}Ar/^{39}Ar$ sanidine ages of ignimbrites inn the Thirtynine Mile volcanic field, Colorado: [abst]: Eos, 1992 Spring Meeting Supplement.
Merrill, G.P., 1897, A treatise on rocks, rock-weathering and soils: New York, Macmillan, 411 p.
Morse, D.G., 1979, Paleogeography and tectonic implications of the late Cretaceous to middle Tertiary rocks of the southern Denver Basin, Colorado:

Baltimore, MD, Johns Hopkins University, unpublished PhD thesis, 344 p.
Morse, D.G., 1985, Oligocene paleogeography in the southern Denver Basin, *in* Flores, R.M., and Kaplan, S.S., eds., Cenozoic paleogeography of the west-central United States, Rocky Mountain Paleogeography Symposium 3: Rocky Mountain Section, Society of Economic Paleontologists and Mineralogists, Denver, Colo., p. 277-292.
Nichols, D.J. and Fleming, R.F., 2002, Palynology and palynostratigraphy of Maastrichtian, Paleocene, and Eocene strata in the Denver Basin, Colorado, *in* Johnson, K.R., Raynolds, R.G., and Reynolds, M.L., eds., Paleontology and stratigraphy of Laramide strata in the Denver Basin: Rocky Mountain Geology (The Denver Basin Issue), v. 37 no. 2.
Rasely, R.C. and Petersen, M.M., 1998, Geologic hazard evaluations; pre-fire and post-fire watershed sediment yield modeling of rangeland and mountain geomorphic units using the PSIAC (rev. 1991) sediment yield model, in Proceedings of the Conference on Geologic Hazards and Engineering Practices in Western Colorado, October 29 and 30, 1998: Colorado Geological Survey.
Raynolds, R.G., 1997, Synorogenic and post-orogenic strata in the central Front Range, Colorado, *in* Bolyard, D.W., and Sonnenberg, S.A., eds., Geologic history of the Colorado Front Range: Rocky Mountain Association of Geologists, p. 43-48.
Raynolds, R.G., 2001a, Evidence for episodic orogenic activity on the Front Range: Denver Basin Project Spring Science Meeting, Denver, Colo., May 18. 2001, unpublished conference abstract.
Raynolds, R.G., 2001b, Episodic deposition in the Cretaceous and Paleocene Denver Basin; How tectonics controls the continuity of the stratigraphic record [abst.]: Geological Society of America Abstracts with Programs, v. 33, no. 6, p. A197.
Raynolds, R.G., 2002, Upper Cretaceous and Tertiary stratigraphy of the Denver Basin, Colorado, *in* Johnson, K.R., Raynolds, R.G., and Reynolds, M.L., eds., Paleontology and stratigraphy of Laramide strata in the Denver Basin: Rocky Mountain Geology (The Denver Basin Issue), v. 37 no. 2.
Remane, J., Faure-Muret, A., and Odin, G.S., 2002, International stratigraphiic chart: International Union of Geological Sciences and UNESCO Commission on the Geological Map of the World.
Reynolds, M.L., Johnson, K.R., and Thomasson, J.R., 2001, A diverse megaflora from the early Paleocene synorogenic strata in the Denver Basin, Colorado Springs, Colorado [abst.]: Geological Society of America, Abstracts with Programs, v. 33, no. 6, p. A198.
Richardson, G.B., 1912, The Monument Creek Group: Geological Society America Bulletin, v. 23, p. 257-276.
Richardson, G.B., 1915, Castle Rock folio, Colorado, U.S. Geological Survey Geologic Atlas Folio 198, 19 p.
Robson, S.G., 1987, Bedrock aquifers in the Denver Basin, Colorado; a quantitative water-resources appraisal: U.S. Geological Survey Professional Paper 1257, 73 p., scale 1:500,000.
Robson, S.G., 1989, Alluvial and bedrock aquifers of the Denver basin; eastern Colorado's dual ground-water resource: U.S. Geological Survey Water-Supply Paper 2302, 40 p.
Rogers, W.P., Ladwig, L.R., Hornbaker, A.L., Schwochow, S.D., Hart, S.S., Sheldon, D.C., Scroggs, D.L., and Soule, J.M., 1974, Guidelines and criteria for identification and land-use controls of geologic hazard and mineral resource areas: Colorado Geological Survey Special Publication 6, 146 p..
Rowley, P.D., Himmelreich, J.W., Jr., and Kupfer, D.H., 2002, Geological map of the Cheyenne Mountain quadrangle, El Paso County, Colorado: Colorado Geological Survey Open-file Report 02-05, scale 1:24,000,
Schwochow, S.D., Shroba, R.R., and Wicklein, P. C., 1974, Atlas of sand, gravel, and quarry aggregate resources, Colorado Front Range Counties: Colorado Geological Survey Special Publication 5-B,
Scott, G.R., and Wobus, R.A., 1973, Reconnaissance geologic map of Colorado Springs and vicinity, Colorado: U.S. Geological Survey Miscellaneous Field Studies Map MF-482, scale 1:62,500.
Soister, P.E., 1968, Geologic map of the Corral Bluffs quadrangle, El Paso County, Colorado: U.S. Geological Survey Geologic Quadrangle Map GQ-783
Soister, P.E., and Tschudy, R.H., 1978, Eocene rocks in the Denver Basin, *in* Pruit, J.D., and Coffin, P.E., eds., Energy resources of the Denver Basin: Denver, Colo., Rocky Mountain Association of Geologists, 29th Annual Field Symposium Guidebook, p. 231–235.
Soule, J.M., 1978; Geologic Hazards in Douglas County, Colorado: Colorado Geological Survey Open-File Report OF-78-5.

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

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

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

Trimble, D.E., and Fitch, H.R., 1974, Map showing potential sources of gravel and crushed-rock aggregate in the Colorado Springs-Castle Rock area, Front Range urban corridor, Colorado: U.S. Geological Survey Miscellaneous Investigations Series Map I-857-A, scale 1:100,000.

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

Trimble, D.E., and Machette, M.N., 1979b, Geologic map of the greater Denver area, Front Range urban corridor, Colorado: U.S. Geological Survey Miscellaneous Investigations Series Map I-856-H, scale 1:100,000.

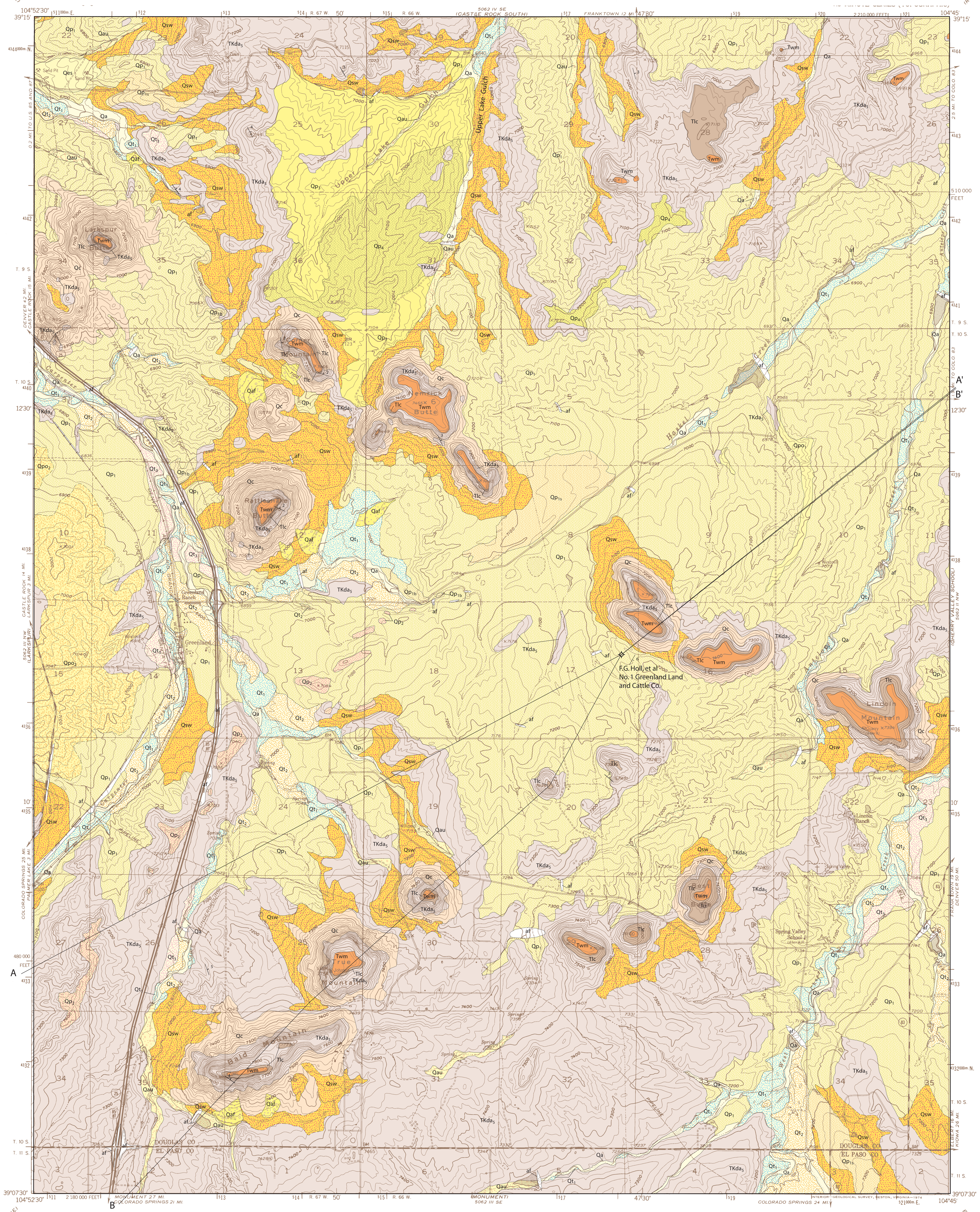
Varnes, D.J., and Scott, G.R., 1967, General and engineering geology of the United States Air Force Academy site, Colorado, with a section on Ground water by W.E.D. Cardwell and E.D. Jenkins: U.S. Geological Survey Professional Paper 551, 93 p.

Wobus, R.A., and Scott, G.R., 1977a, Reconnaissance geologic map of the Woodland Park quadrangle, Colorado: U.S. Geological Survey Miscellaneous Field Studies Map MF-842, scale 1:24,000.

Wobus, R.A., and Scott, G.R., 1977b, Reconnaissance geologic map of the Cascade quadrangle, El Paso County, Colorado: U.S. Geological Survey Open-File Report 77-138, scale 1:24,000.

COLORADO GEOLOGICAL SURVEY
DIVISION OF MINERALS AND GEOLOGY
DEPARTMENT OF NATURAL RESOURCES
DENVER, COLORADO

OPEN FILE MAP 03-9
GEOLOGIC MAP OF THE GREENLAND QUADRANGLE,
DOUGLAS COUNTY, COLORADO
Booklet accompanies map
DOI: https://doi.org/10.58783/cgs.of0309.ooht8831



Base from U.S. Geological Survey, 1975
Polyconic projection, 1927 North American Datum
10,000-foot grid based on Colorado coordinate system, central zone
1,000-meter Universal Transverse Mercator grid ticks, zone 13

UTM GRID AND 1975 MAGNETIC NORTH DECLINATION AT CENTER OF MAP
DIAGRAM IS APPROXIMATE

SCALE 1:24,000

QUADRANGLE LOCATION

Geology mapped in 2002
Cartography by Karen Morgan

LIST OF MAP UNITS

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

SURFICIAL DEPOSITS

HUMAN-MADE DEPOSITS

- af — Artificial fill (late Holocene)

ALLUVIAL DEPOSITS

- Qa — Channel and flood-plain alluvium (late Holocene)
- Qt_1 — Terrace alluvium one (Holocene and late Pleistocene)
- Qt_2 — Terrace alluvium two (late Pleistocene)
- Qt_3 — Terrace alluvium three (late Pleistocene)
- Qau — Alluvium, undivided (Holocene and Pleistocene)
- Qsw — Sheetwash (Holocene and late Pleistocene)
- Qaf — Alluvial-fan deposits (Holocene and late Pleistocene)
- Qp_1 — Older alluvium one (late Pleistocene)
  - Qp_{1b} — Local areas of Qp_1 containing large boulders of arkose or conglomerate
  - Qp_{1s} — Local areas of Qp_1 sand
- Qp_2 — Older alluvium two (middle Pleistocene)
- Qp_3 — Older alluvium three (middle? Pleistocene)
- Qp_4 — Older alluvium four (early? Pleistocene)
- Qpo_1 — Older alluvium one undifferentiated (Pleistocene)
- Qpo_2 — Older alluvium two undifferentiated (Pleistocene)

MASS-WASTING DEPOSITS

- Qc — Colluvium (Holocene and late Pleistocene)

EOLIAN DEPOSITS

- Qes — Eolian sand (middle and late Holocene)

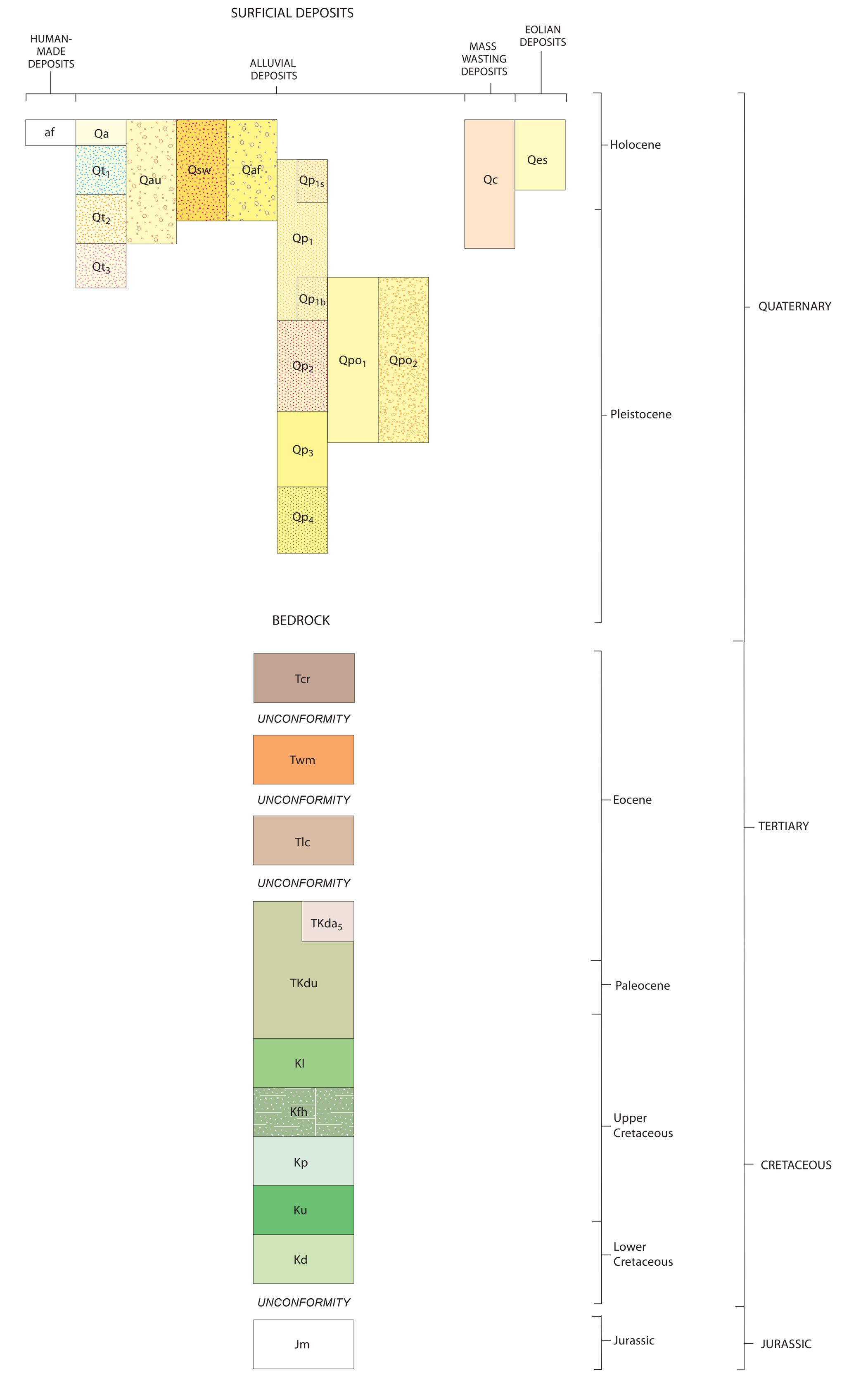
BEDROCK DEPOSITS

- Tcr — Castle Rock Conglomerate (late Eocene)
- Twm — Wall Mountain Tuff (late Eocene)
- Tlc — Conglomerate of Larkspur Butte (late? Eocene)
- Dawson Formation (Upper Cretaceous to Eocene)
  - Upper part of the Dawson Formation (Upper Creta- ceous to Eocene)
    - $TKda_5$ — Facies unit five (early to middle? Eocene)
  - TKdu — Dawson Formation, undivided (Upper Cretaceous to Eocene)—Shown only on cross section
- Kl — Laramie Formation (Upper Cretacecous)—Shown only on cross section
- Kf — Fox Hills Sandstone (Upper Cretaceous)—Shown only on cross section
- Kp — Pierre Shale (Upper Cretaceous)—Shown only on cross section
- Ku — Older Cretaceous undivided (lowermost Upper Creta- ceous and Lower Cretaceous)—Shown only on cross section
- Kd — Dakota Group undivided (Lower Cretaceous)—Shown only on cross section
- Jm — Morrison Formation (Jurassic)—Shown only on cross section

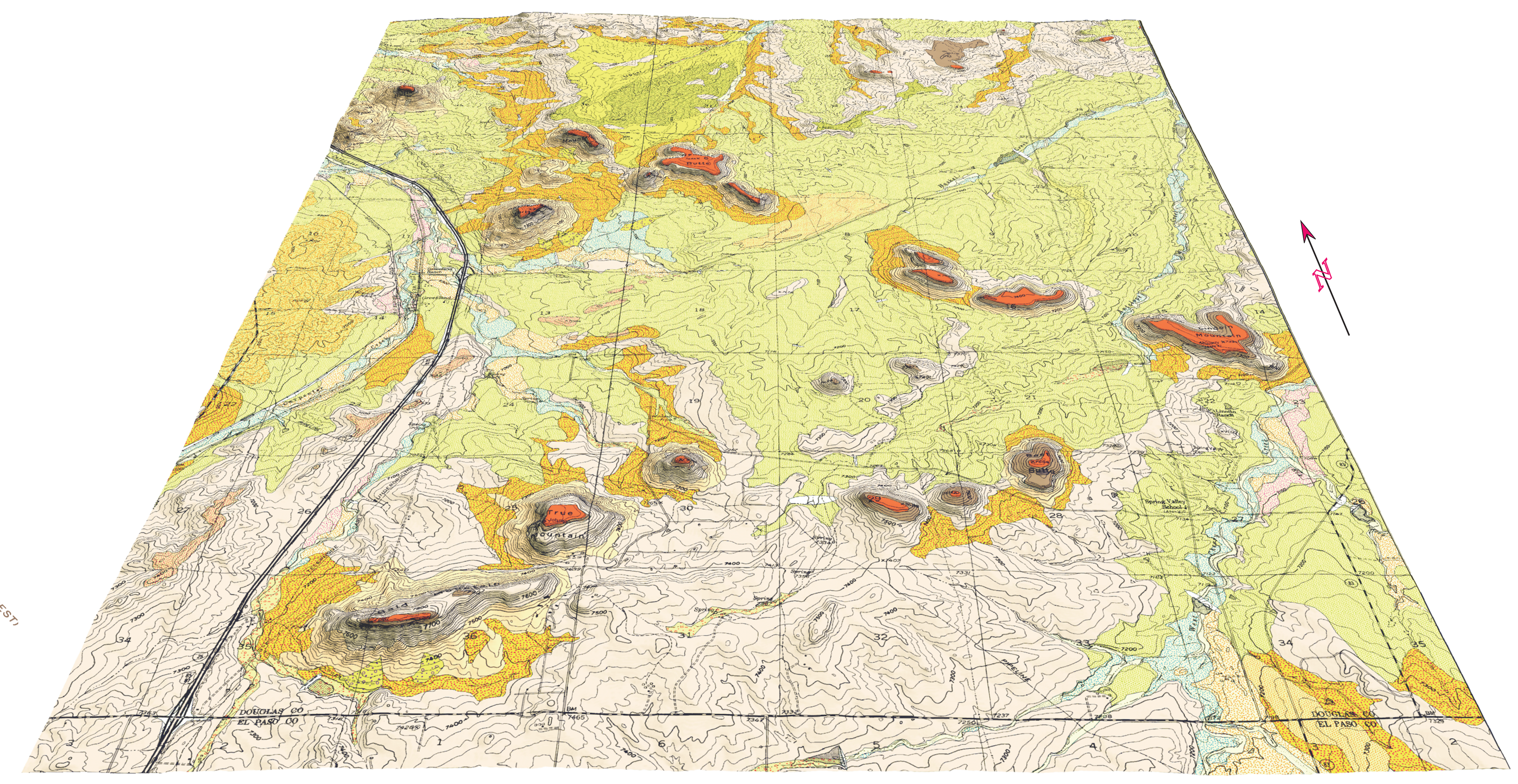
MAP SYMBOLS

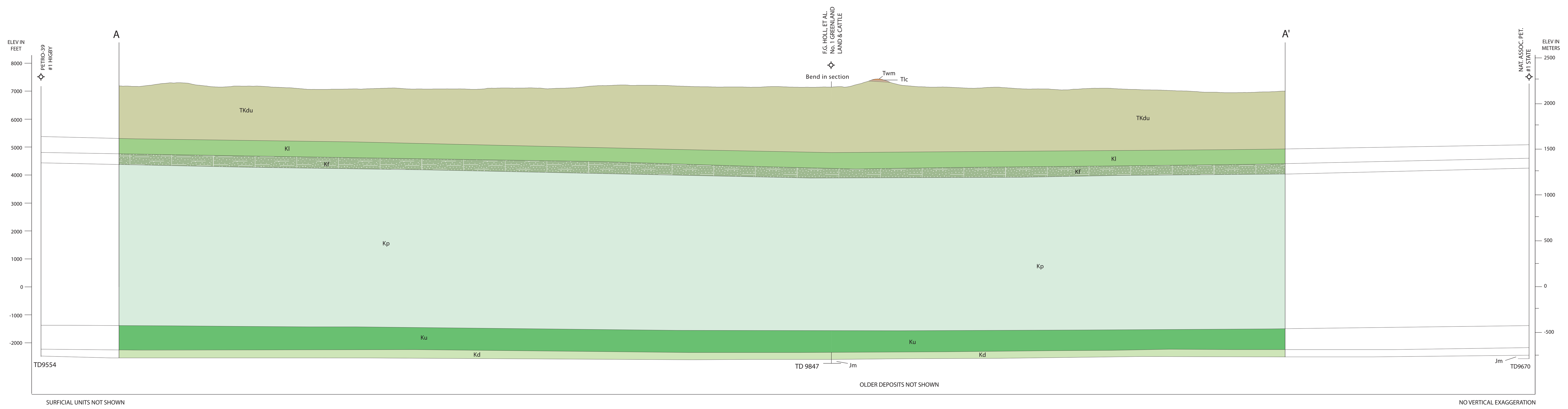
- Contact—Dashed where approximately located
- Strike and dip of inclined beds—Angle of dip shown in degrees
- Alignment of cross sections (A—A')
- Abandoned petroleum test well

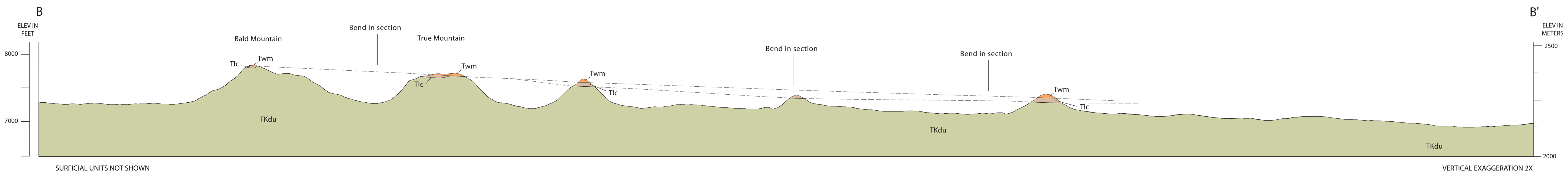
CORRELATION OF MAP UNITS



SHADED-RELIEF MAP OF THE GREENLAND QUADRANGLE WITH GEOLOGY OVERLAY; OBLIQUE VIEW LOOKING NORTH







Bill Owens, Governor
State of Colorado

Russell George, Executive Director,
Department of Natural Resources

Ronald W. Cattany, Director,
Division of Minerals and Geology

Vincent Matthews, State Geologist

GEOLOGIC MAP OF THE GREENLAND QUADRANGLE, DOUGLAS COUNTY, COLORADO

By Jon P. Thorson

2003