

GENERALIZED SURFICIAL GEOLOGIC MAP OF THE DENVER 1° × 2° QUADRANGLE, COLORADO

Compiled by
David W. Moore, Arthur W. Straub, Margaret E. Berry, Michael L. Baker, and
Theodore R. Brandt

2001

CONTENT AND PURPOSE

This map locates surficial geologic deposits of Quaternary age in the greater Denver area and surrounding region. Physical properties of the deposits are described. The physical properties include dominant grain size, composition, potential to expand upon sorption of water, and others. Origins and ages of the deposits, and their inherent geologic hazards are identified. The properties of deposits and materials on and near the land surface affect its suitability for societal uses. Examples of such use include large-scale landfill sites, gravel pits and rock quarries, large-scale residential developments, greenbelts, utility lines, and roads. Planners, zoning officials, builders, and interested citizens should have a clear grasp of how the properties of surficial deposits affect the growing urban sector within the Denver 1° × 2° quadrangle. This map provides basic data that can be used to derive other maps that show suitability of land for specific purposes.

Apart from its usefulness to urban planning, the map can be a tool for the management and research of natural resources. It can enhance ecological surveys that were made by using satellite imagery. Certain biogeographical habitats, for example foothill woodlands and alpine forests, are influenced by soil-related factors and correlate well with certain units on this map. Other map data such as the ages and origins of the Quaternary surficial deposits are essential to any geomorphologic study of the Denver quadrangle.

MAP UNIT NAMES

The map unit names derive from a classification of geologic surficial materials. The names are based on prevalent grain size, minerals (or rock types), and geologic origin. Examples are “bouldery crystalline-

rock landslide deposit” and “stabilized dune sand.” Large areas (generally >1 km²; >0.4 mi²) of exposed bedrock, mostly devoid of surficial materials, are mapped with a symbol “R.”

PARTICLE SIZE AND COLOR TERMINOLOGY

We used geological and soil textural terms to describe the size of particles in the surficial deposits. Particle sizes ranged from microns to meters in diameter. The combined use of geologic and soil terminology resulted from a necessity to consult various data sources to characterize the materials. **Clasts** are particles larger than 2 mm in diameter. We used geologic terms to describe clasts. Particles 2 mm or smaller in diameter make up the **matrix** of the deposits. Both geologic and agronomic terms are used to describe the matrix.

The clasts are divided into granules (>2 mm–4 mm; >1/12–1/6 in.), pebbles (>4–64 mm; >1/6–2.5 in.), cobbles (>64–256 mm; >2.5–10 in.), and boulders (>256 mm; >10 in.) (see Bates and Jackson, 1980). The matrix consists of three particle-size classes: clay (<1/256 mm; <0.00016 in.), silt (1/256–1/16 mm; 0.00016–0.0025 in.), and sand (>1/16–2 mm; >0.0025–0.08 in.). Terms like “sandy silt” and “gravelly sand” reflect visual estimates by geologists. We accepted some of these terms from previously published reports and assigned some terms ourselves. For this purpose we compared samples from deposits to standard grain-size samples on an American Geological Institute chart.

We also used soil science terms to characterize the matrix. For example, “clay loam” conforms to U.S. Department of Agriculture (USDA) terminology in the Soil Survey Manual (Soil Survey Staff, 1951). These are **soil textural class** names (fig. 1), and they

describe the proportions of sand, silt, and clay. Soil survey reports identified the soil textural class of the C horizon and parent materials in selected areas that we mapped.

Our fieldwork required another source of grain-size terms. This terminology used the USDA **field determination** of soil textural class method (Soil Survey Staff, 1951, p. 212). This method requires deformation of samples of the matrix by using the fingers. The manner by which samples deform indicates a basic soil textural class.

Color terms describe clasts and the matrix of materials and deposits. Colors of clasts follow geologic convention. Some terms derive from published reports, and some we assigned from color terms in the Rock Color Chart (Goddard and others, 1970). Colors of the matrix were determined by comparison with the Munsell soil color charts, which are used by soil scientists and Quaternary geologists.

UPLAND MATERIALS

The origin of the names we apply to many deposits, such as “stabilized dune sand,” are obvious. However, we use two terms, “colluvium” and “residuum,” which have several meanings. We define them here for the purposes of our map. Colluvium and residuum cover hillslopes and uplands, respectively. **Colluvium** is unconsolidated rock detritus and soil material that was very slowly transported and deposited on slopes, mainly by gravity (some detritus also was removed by runoff). Because colluvium creeps downslope, hillslopes covered by it may be unsuitable and costly slope-stabilization work may be required. Colluvium is mapped in areas dominated by hillslopes steeper than about an 8 percent ($4^{\circ} 34'$) gradient and mapped in areas larger than 2 km^2 (0.77 mi^2). **Residuum** was derived primarily by in-place disintegration of exposed rock, and surface processes have not transported the material significantly. We mapped residuum on nearly level land that lacks widespread deposits of other origins. It was not mapped on slopes steeper than about 8 percent. Eight percent is a standard slope category boundary in the USDA land classification (Soil Survey Staff, 1951, p. 163). That system separates level and nearly level land from more sloping land. The system is consistent in the USDA county soil reports (for example, Larsen and Brown, 1971), as is our distinction of colluvium and residuum on the surficial geologic map.

METHOD OF MAPPING

We generalized the boundaries of some units on this map from some geologic unit boundaries shown on the “Geologic Map of the Denver $1^{\circ} \times 2^{\circ}$ Quadrangle” (Bryant and others, 1981). Many of our unit boundaries, however, were drawn on the basis of our field observations and on our verification of the boundaries shown on other published, detailed geologic maps. Also useful were agronomic soil maps on which a soil unit or units correspond to a surficial geologic unit, because both soils and geologic units correspond closely to landforms. Our geologic map unit descriptions incorporate color, grain size, thickness, and chemical data from the weathered zone (C soil horizon) immediately above bedrock, or non-soil, unconsolidated deposit. We did not incorporate properties of the solum (A and B horizons) of modern soils that are in the surficial deposits and materials.

Diverse residual, colluvial, eolian, and alluvial deposits and materials are present in the quadrangle. In general, the most widespread of these was mapped in a polygon. Consequently, materials or deposits other than the prevalent one may be present in a mapped area. Some users of the map may wish to grasp the diversity of surficial deposits and materials in relatively small areas of the quadrangle. This may be accomplished by examining certain detailed geologic maps, for example those of Malde (1955) and Machette (1977).

The user should not extend the generalized map data into small areas without consulting supplemental data. Our map does not show the variation of deposits at the scale of most home and commercial construction sites. In general, soils engineers and engineering geologists should investigate specific sites prior to construction.

BASE MAP

The Denver $1^{\circ} \times 2^{\circ}$ topographic quadrangle map (scale 1:250,000, prepared by the Defense Mapping Agency Topographic Center, Washington, D.C., 1953, revised 1978) is the base for our digital surficial geologic map. In making this digital map, we scanned the base, printed as black lines on clear film, on a large-format scanner to make a raster image (tiff file). The image file was georeferenced and imported into a computer-aided drawing program to make the map layout. The original 1978 paper base map shows roads, streams, place names, and contours printed in different colored inks. The published paper map, thus, may be easier for some users to read than the all-gray scanned base.

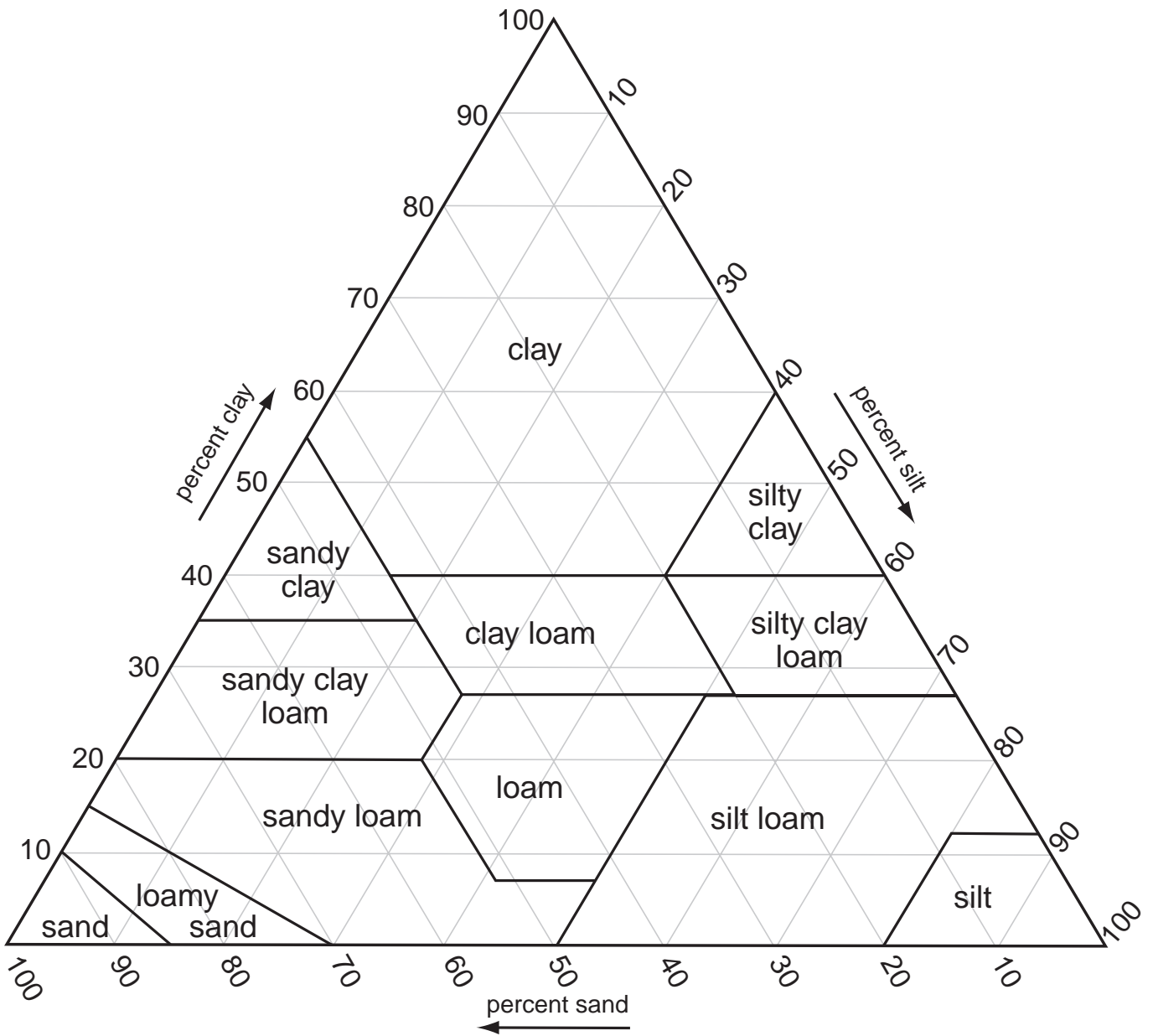


Figure 1. Chart showing the percentages of clay, silt, and sand in the basic soil textural classes (Soil Survey Staff, 1951).

ACKNOWLEDGMENTS

This map is based in part on the mapping of Bryant and others (1981), but it differs from the latter in that it focuses on the unconsolidated, geologically young, surficial deposits and materials. We thank Bruce Bryant for the loan of his original map and for his discussions about rocks and surface deposits in the Colorado Front Range. Glenn Scott, Dan Muhs, and Rich Madole kindly shared first-hand knowledge and unpublished information. We thank Ted Brandt for his assistance with computer applications, and Diane Lane for advice in preparing the map layout.

DESCRIPTION OF MAP UNITS

HOLOCENE

- afa Alluvial-fan deposit**—Reddish-brown, brown, and brownish-gray, gravelly and clayey sand. Many subangular pebbles, cobbles, and boulders, mostly pink to reddish-tan, biotite or pyroxene-hornblende-biotite monzonite; locally sandstone, limestone, and dolomite. Clast lithologies reflect the source rock lithologies, which vary locally. Tormentally crossbedded gravel is concentrated in the lowest beds; cut-and-fill structures are common. High part of fan (apex and proximal part) is moderately steep and bouldery, and it contains matrix-supported, poorly sorted, debris-flow deposits. Deposit was mapped if >600 m across. Many deposits are a few tens to a few hundred meters in extent, too small to map at the scale of this map. Alluvial-fan deposits accumulate where turbid, rapid-flowing runoff debouches onto nearly level land. Thickness near the center of a deposit may be as much as 5–10 m
- cac Arkosic loamy colluvium and sheetwash alluvium**—Light-gray, reddish-brown, and olive-brown loam, sand, and sandy clay; locally gravelly, including large boulders. Runoff has washed clay from the upper part (upper 5–10 cm), concentrating micaceous, fine- to coarse-grained quartz and feldspar sand. The surficial sand grades downward through oxidized colluvium (loam and clay loam) and weathered rock

20–100 cm thick, to moderately or poorly cemented, interbedded, clayey sandstone, sandy claystone, and siltstone. Particles are mostly quartz, feldspar, granitic rock detritus; andesite is abundant locally. In the Colorado Piedmont south of Denver, and within 10 km of the east front of the mountains (especially in northwest El Paso County west of Monument Creek), the unit includes remnants of intensely weathered, clayey and sandy gravel pediment and terrace alluvium at various high topographic levels above modern streams. Many of the remnants are 150–300 m wide, and are too small to be mapped. Within areas mapped are a few buttes. On the buttes sandstone boulders 0.5–6 m in diameter are scattered on slopes below ledgy outcrops of pale-brown sandstone and conglomeratic sandstone (where such terrain predominates, a bouldery phase, unit **cacb**, was mapped). Moderately to steeply sloping uplands include areas of class 1–2 stoniness and class 2–3 rockiness (Soil Survey Staff, 1951), a discontinuous lag of rounded granules, pebbles, cobbles, and sparse boulders of granite, vein quartz, gneiss, schist, and 2–4 percent moderate-red arkosic sandstone. The map unit includes gently sloping areas veneered by eolian silt and sand (about 1 m thick). The eolian deposits contain slowly permeable clayey layers. Map unit includes channel and floodplain alluvium of intermittent streams, mostly sandy clay to clayey sand, gravelly at the base. A dense network of ravines in the Plum and Cherry Creek drainages (central Douglas County) cuts the colluvium and sheetwash alluvium deposit. In the headwater reaches of a few streams, the unit includes unmapped, fluvial terrace gravel. Scattered, small, unmapped, inactive eolian sand dunes are included in the unit. Colluvium and sheetwash generally are 0.3–1.5 m thick

cacb Bouldery phase of arkosic loamy colluvium—Yellowish-gray, pale-brown, and grayish-brown, gravelly (10–30 percent) loam and clay loam containing weathered, very pale

orange, arkosic, pebbly sandstone and conglomerate boulders. Boulders are abundant on hillslopes below ledgy outcrops. Colluvium contains abundant to common pebbles and cobbles of gneiss, coarse-grained pink granite, and, locally, minor pale-reddish-purple and light-gray welded rhyolitic tuff. Boulders are moderately to well cemented, 0.5–6 m across, and subround to blocky. They cover 20–80 percent of hillslopes. Rockfall and toppling failures of cliffs are a hazard. The colluvium is subject to debris flow during torrential rainfall. Unit occurs on slopes of buttes, mesas, and uplands that are capped by sandstone or tuff. In the Castle Rock area, and in southeast Douglas County and north El Paso County, it locally includes minor angular gravel-size pieces of rhyolitic vitric ash-flow tuff (Wall Mountain Tuff, called “Castle Rock Rhyolite” in the dimension-stone building trade in the late 1800’s). Thickness generally 2–4 m

xch

Clayey, calcareous disintegration

residuum—Dark-grayish-brown, light-yellowish-brown, olive to light-olive-brown, fine, platy shale residuum. Silt, clay, and minor sand are present in variable proportions (clay loam and silty clay loam in the upper meter, and, at increasing depth, silty clay and clay). The residuum is very calcareous, locally micaceous and carbonaceous, and contains limestone concretions. The surface layer generally is pebbly, silty clay loam and silty clay, 1–10 cm thick. Scattered, discontinuous veneers of quartz and feldspar sand granules, rounded pebbles, and small cobbles (chiefly granite and quartz) have accumulated as a surface lag. The residuum is firm or plastic when moist, hard when dry. Unit is generally gypsiferous, and locally it contains small (0.2–1 cm) crystals of selenite (gypsum). The residuum may be saline and alkaline at shallow depth. Residuum is on nearly level to moderately sloping land; locally, it is characterized by low hillocks, and it includes ledgy bedrock outcrops. Locally, the residuum includes

ironstone (reddish-brown, brownish-black, and grayish-red siderite, calcite, and pyrite) and (or) limestone concretions and partly weathered shale bedrock, and shale-chip colluvium. The residuum is deeply cut by ravines and arroyos in places. Residuum grades downward to dark-grayish-brown, olive-gray, weathered shale, silty or sandy claystone, clayey thin-bedded sandstone, chalky shale, silty blocky shale, weathered chalky shale, or disintegrated platy limestone. In some places residuum is thin on silty, hard, very dark gray shale that contains thin beds (1–10 cm thick) of bentonitic clay. Where these beds dip about 30° or more, they are susceptible to differential expansion toward the land surface (“heaving”), owing to sorption of water by the clay minerals. Map unit includes zones of ledge-forming platy, moderate-yellowish-orange limestone concretions as much as 2–4 m in diameter. Unit is approximately 0.5–1.5 m thick

HOLOCENE AND LATE PLEISTOCENE

Disintegrated deposits and periglacial deposits, bouldery till, and rock outcrop

outcrop—Disintegrated, nonsorted, blocky deposits in high alpine and montane glaciated areas. Silt to boulders; matrix commonly is sandy and micaceous. Angular rock fragments form talus cones and aprons, protalus ramparts, rock-glacier deposits, block fields, solifluction or frost-heave deposits, colluvium, fan alluvium, and debris-flow deposits. The deposits vary in genesis in short lateral distances. Map unit includes some small, discontinuous deposits of bouldery Pinedale till and scattered erratic clasts on glacier-scoured bedrock. Excludes till in large end and lateral moraines (mapped separately as tb units). Clasts generally are angular, subangular, or subrounded; in some places boulders are larger than 5 m in diameter. Map unit locally includes minor sheetwash alluvium and small areas of lake silt and sand in glacially excavated lake basins. Map unit includes bare bedrock on some ridges

	<p>and massive peaks. Till, rock glacier deposits, and local lake deposits are present in ice-carved basins at heads of valleys. Talus accumulates on and below steep valley sides. Colluvium, solifluction deposits, and frost-heaved deposits locally cover gently or moderately sloping uplands, high tundra-covered surfaces, and moderate slopes on valley sides. Locally, includes deposits of alpine debris flows and mudflows. Snowmelt and heavy rain triggers debris flows (Curry, 1966). Debris-flow deposits, composed of randomly oriented, angular gravel supported in a fine-grained matrix, form fans, lobate aprons, and concentric constructional ridges at the bases of steep slopes. More extensive lichen cover, more well developed soil, and more pronounced rock weathering phenomena characterize the older disintegrated deposits that are included in this map unit. The youngest (Holocene) deposits range from unoxidized deposits lacking soil development, to oxidized deposits that have weakly developed B soil horizons. Thin loess covers some of the older deposits. Locally, the unit includes disintegrated deposits that accumulated during the Little Ice age (A.D. 1450–1850), the neoglacial interval (younger than 6,000 yrs), and early Holocene to late Pleistocene (Richmond, 1986)</p>	<p>boulders exceed 5 m in diameter. The surface soil on scree locally is dark-brown silt and sand 8–12 cm thick, enriched in organic matter. Below this is 20–30 cm of yellowish-brown sandy gravel containing as much as 20 percent silt and clay. Deposits are 1.5–8 m thick on fractured bedrock</p>
dba	<p>Crystalline-clast deposits— Disintegrated deposits, periglacial deposits, and bouldery till that are composed mostly of Precambrian rock (granite, hornblende, biotite, and felsic gneiss, quartz monzonite, and granodiorite) or Tertiary intrusive rock (light-gray and white quartz monzonite and porphyritic rhyolite). Matrix is absent in coarse talus and is present in most other deposits. Matrix generally is gray and grayish-brown or yellowish-brown silt to coarse sand; typically micaceous. Scree on steep slopes above timberline on a typical Tertiary intrusive mass (for example, Red Mountain, south of Berthoud Pass) is composed of angular and subangular clasts, mostly 10–30 cm in diameter; 2–5 percent of clasts are about 1 m across. A few</p>	<p>Mixed-lithology-clast deposits— Disintegrated deposits, periglacial deposits, and bouldery till that have mixed bedrock lithologies. Mapped in the Mosquito Range (west boundary of map area) where various lithologic source rocks produce deposits containing fragments of mixed lithology. Clasts are Precambrian granite, gneiss, and migmatite, Tertiary intrusive rock, and Paleozoic sandstone, conglomerate, shale, limestone, dolomite, and quartzite</p> <p>asa Alluvial sand, silt, clay, and gravel (post-Piney Creek alluvium, Piney Creek Alluvium, and pre-Piney Creek alluvium of Hunt, 1954, and Scott, 1960); Broadway Alluvium— Underlies flood plains and low stream terrace surfaces (mapped only where width is >0.2 km). In the flood plain of the South Platte River the deposit overlies older alluvium (ags). Low parts of mapped areas are susceptible to stream flooding. Following a general description of alluvium in the quadrangle, alluvium of the South Platte River is described. General description: Light-yellowish-gray, grayish-brown, moderate-brown, locally reddish-brown, quartz sand and sandy gravel; sand commonly includes feldspar and mica particles. Commonly dark-gray and dark-grayish-brown noncalcareous silt and clay layers are thick and persistent in upper 0.4–2 m; grades downward to yellowish-brown, calcareous, moderately alkaline loam and sandy loam at a depth of 2–4 m. Sandy rounded gravel or gravelly sand at base. In or near (as far as 15 km east of) the mountains, 40–70 percent of the alluvium is gravel; 10–30 percent of the gravel typically is cobbles and boulders (Trimble and Fitch, 1974). The flood-plain and channel alluvium interfingers laterally with fan</p>

alluvium and colluvium. Poorly to well stratified, planar bedded and crossbedded. Upper 0.5 m commonly is gray, humic-rich (as much as 10 percent by volume), silty, very fine to fine sand, especially in flood plains of tributary streams (Simpson, 1973b). Gravel deposited by rivers that head in the mountains typically is rounded granitoid plutonic rock, including biotite and hornblende-biotite granite, biotite gneiss, felsic gneiss, schist, and local quartzite, metaquartzite, mafic-rich intrusive rock, amphibolite, and hornblende schist. Granite and quartzite gravel is a valued aggregate for concrete and road metal because the clasts are sound and in places the deposits contain little interstitial lime and few or no reactive constituents (Trimble and Fitch, 1974). In deposits of rivers that drain glaciated terrain (for example, Clear and Bear Creeks, and the South Platte River), beds of massive, clast-supported gravel alternate with thinly bedded sand and organic-rich sediment (Madole, 1991). Deposits of rivers that drain unglaciated terrain contain mostly pebbles of quartz, sandstone, limestone, feldspar, calcium carbonate (caliche), marl, and shale in a sandy matrix. In the southwest corner of quadrangle (east and south of Fairplay), the gravel is mostly hypabyssal igneous rocks, felsic porphyry, maroon arkosic sandstone and siltstone, scarce quartz and schist, medium-gray limestone, and aphanitic igneous rock. Locally, the alluvium of major rivers includes discontinuous silty and clayey beds as thick as 4 m.

Alluvium of the South Platte River: in Denver, Broadway Boulevard is on a Broadway alluvial terrace. The following is a description of Broadway Alluvium, of late Pleistocene age, exposed in a fluvial terrace 8–10 m above the river and 0.8 km east of it, near Highway C–470 in Littleton: brown, grayish-brown, and moderate-yellowish-brown (reddish-brown locally) pebbly, silty, micaceous sand. Fine to very coarse sand, rounded granules (~30 percent), rounded pebbles and

cobbles of granite, biotite-quartz gneiss, quartz, ironstone, feldspar, welded tuff, and minor amounts of chert, sandstone, quartzite, altered amphibolite, aplite, and pegmatite. The alluvium is veneered by fine sand washed onto the terrace from small side-valley drainageways. Thickness of the alluvium is 5–7 m along Santa Fe Avenue in Littleton. Younger Holocene alluvium generally is chiefly pebbly quartz sand. Some older deposits of Holocene age have minor accumulations of secondary calcium carbonate. Some deposits contain sparse fossil bones of bison and mule deer. The upper part of the alluvium in modern flood plains is humic and fine grained.

In Denver County, **asa** alluvium of the South Platte River generally is 6–12 m thick (it overlies thicker, older alluvium of similar composition), is about half sand and half gravel, and the gravel is composed mostly of granite, pegmatite, quartz, and minor gneiss and schist. Thick interbeds of clay are present locally. In small tributary valleys, the alluvium is 2–4.5 m thick. Beneath the Monument Creek flood plain the alluvium is about 3 m thick

ed Stabilized dune sand—Grayish-brown (at surface), light-yellowish-brown, and yellowish-gray, very fine to medium quartz sand and loamy sand (3/8–3/16 mm diameter, Muhs and others, 1996). In some places the deposit is 10–15 percent clay and 10–30 percent silt. The dune sand is moderately well sorted, subangular to rounded, quartz and feldspar sand grains. Sand is calcareous below about 1-m depth; locally, the deposit contains white calcium carbonate and sodium bicarbonate in soft masses. On the Great Plains in uncultivated areas, dunes downwind from rivers and their major tributaries are stabilized by vegetation (commonly sand sage, *Artemisia filifolia*). Dune sand forms gently rolling land (3–20 percent slopes), stabilized parabolic dunes (arms point northwest), and irregular hilly to hummocky terrain; dunelike uplands having no external drainage commonly are 3–10 m higher than the

adjacent river valley. Scattered blowout depressions and minor active dunes indicate that the deposit is susceptible to wind erosion. Common bedding types in the deposit are massive bedded, planar bedded, and low-angle crossbedding. Dune sand locally contains buried discontinuous calcium carbonate-cemented layers, organic-rich silt layers, and (or) buried paleosols. These features suggest that intervals of dune building were interrupted by periods of stability. Intervals of dune formation may have been characterized by a copious supply of sand, persistent strong winds, and (or) relatively sparse vegetation. Recent studies in eastern Colorado indicate that there were several intervals of dune building during the past 20,000 yrs. The presence of buried soils, changes in fossil pollen, and ages obtained by radiocarbon and thermoluminescent dating techniques indicate reactivation of dunes about 6,000, 4,500, and 1,000 yrs ago, and a longer episode of dune formation during the last glacial cycle extended from 20,000–12,000 yrs ago (Forman and others, 1995). Reduced grass cover associated with regional drought can cause reactivation of dunes. Other studies (Madole, 1994; Muhs and others, 1997) indicate that upper parts of the dune deposits in the northeast part of the quadrangle and in Nebraska accumulated less than 1,000 yrs ago, possibly as recently as during the last two centuries. Where the deposit is thin, overlying the Denver and Dawson Formations (bedrock), excavations may encounter expansive clay minerals in underlying weathered claystone. Thickness generally 3–10 m

es **Eolian sand**—Yellowish-brown, dark-yellowish-brown, and light-olive-brown, chiefly very fine to medium quartz sand; some coarse sand and, locally, silty and slightly clayey sand. Well to moderately well sorted. Less than 5 percent feldspar grains, 2–5 percent lithic grains, and about 2 percent heavy mineral grains. Sand is generally a sheetlike deposit. Locally, it includes sand in stabilized dunes and degraded parabolic dunes. Some

deposits have characteristic large-scale crossbedding. The upper part of the eolian sand commonly contains a well-developed Brown soil (formerly a Great Soil group of zonal soils having brown surface and light-colored subsurface zones over an accumulation of calcium carbonate; now classified as Ustoll or Xeroll soil). With regard to the age of the eolian sand, Scott and Lindvall (1970) stated that “we believe it was deposited starting in Pinedale time and ending when the ‘Altithermal’ soil was formed ca. 4,500 yrs ago.” Eolian sand covers areas of nearly level to very gently undulating land. It includes small areas of vegetated, stabilized, dunes and blowout depressions (not mapped) and imparts a large-scale (township in size) landform grain that is elongated in a northwest-southeast direction. The deposits mantle uplands, mainly downwind from river valleys of the Colorado Piedmont and High Plains. Along the South Platte River the unit overlies older Broadway Alluvium. In general, grain size decreases from northwest to southeast, grading to a mantle of windblown silt and sandy silt (elb) or thinning to scattered thin deposits that mix with, and are separated by, sandy and silty sheetwash alluvium and residuum. In metropolitan areas, eolian landforms are leveled for building purposes. Where the deposits thinly cover the Denver and Dawson Formations (bedrock), excavations may encounter expandable materials (for example, along Highway C–470 east of Chatfield Reservoir in northernmost Douglas County). Thickness generally less than 6 m; as thick as 12–15 m east of the South Platte River between Denver and Brighton, at north edge of map area

jea **Slump-block, earthflow, and mudflow landslide deposits**—Products of gravitational downslope movement of partly disaggregated sedimentary bedrock and (or) surficial materials. Bedrock sources of most deposits are poorly cemented shale, marl, clayey sand, mudstone, or claystone, commonly interbedded with

sandstone or thin limestone. Colors and compositions of the deposits are those of the source rock and (or) surficial materials that were transported. In some places, deposits include clayey disintegration residuum and sheetwash alluvium, and may include hard, rounded gravel derived from alluvial-terrace deposits. Matrix variable, but commonly it is silty and clayey sand to sandy clay. Landslide deposits derived from Cretaceous claystone and weathered shale, locally contain expansive clay minerals and have high potential for swelling upon sorption of water (Hart, 1974). Landslide deposits are unstable, have low compressive strength, and are poor foundation materials for man-made structures.

Slump-block deposits—Masses of bedrock and unconsolidated materials that have rotated or slid downslope as a unit, with little or no flow; properties of materials are not greatly altered, and original bedding, textures, and sedimentary structures of the slumped materials are retained. On the flanks of North and South Table Mountains (near Golden), disoriented blocks of sandstone, claystone, and mafic latite are mixed with fine surficial material that is predominantly silt- and clay-size particles. Scarps that may extend tens or hundreds of meters across the slope commonly mark the upslope limits of slump-block deposits. Low, hummocky ridges are separated by depressions that may contain bogs. Some deposits are stable and grass-covered. Some previously stable slump deposits tend to move again during wet periods. For example, in 1998, an El Niño year, paved streets, utilities, and several large, new homes on the northwest flank of Green Mountain (18 km, or 11 mi west of the State Capitol) were severely damaged because an old landslide deposit became active. In February 2000 these damaged homes were demolished and removed by work crews. Thickness 2–20 m

Earthflow deposits—Heterogeneous mixtures of clay, silt, and sand containing scattered clasts. Plastic

movement of saturated material and slumping of coherent rock or soil masses combine to move masses downslope slowly. Some deposits are chiefly reworked slump-block deposits; others are mostly reworked sheetwash alluvium or colluvium. Very recently active deposits commonly have an abrupt scarp at their upslope limits and crevassed, bulbous, masses at the downslope limit. Thickness 1–5 m

Mudflow deposits—Chaotic, matrix-supported mixtures of clay, silt, and sand and rock fragments. Emplaced by rapid flow of saturated, unconsolidated soil, rock fragments, and weathered shale or mudstone. Most mudflow deposits form lobate, fanlike landforms in areas of weathered shale, mudstone, and interbedded sandstone, thin limestone, and shale. Thickness 1–5 m

ccd **Calcareous clayey colluvium**—Dark-gray and olive-gray clay, silty and sandy clay. Locally includes fragments of white and light-gray chalky shale or clayey limestone, sandstone gravel, and (or) discontinuous lag deposits of crystalline rocks. In some areas, colluvium is 5–10 percent granules or chips of grayish-brown shale and, locally, clayey limestone or marl, and masses of secondary calcium carbonate. Moderately alkaline; locally gypsiferous. Clay minerals include mixed-layer illite-montmorillonite, montmorillonite or smectite (20–40 percent), illite (15–30 percent), kaolinite (10–15 percent), and minor chlorite. Consistency of the colluvium matrix varies with moisture content; it is very hard when dry, sticky and plastic when wet. Slow internal drainage. The map unit includes small, unmapped areas of residuum (xch) on nearly level land. These nearly level areas also include scattered veneers of sheetwashed silty, fine sand. The ccd unit grades downward to gray and olive-gray shale, claystone, and very clayey siltstone. In some places, swelling of the colluvium and heaving of claystone layers under the colluvium have damaged homes,

pavement, and utilities that were built on or in these materials. Most of the recent damage has occurred in the urban corridor east of the Colorado Front Range (in Douglas, Jefferson, and Boulder Counties). The repairs have cost tens of millions of dollars (Noe, 1997). Where the colluvium has a high content of expandable clay minerals, the colluvium expands volumetrically as platy clay minerals and exchangeable ions take up water. The closely related problem of heaving ground occurs in shallow dipping, bedrock that underlies thin colluvium. Locally, expansive claystone can swell along certain beds as water is sorbed by the clay minerals following load removal (for example, after excavation of overburden for building purposes). This is especially true where the dip of bedding exceeds 30°. East of the Indian Hills area and the Dakota Hogback (southwest of Denver in north-central Jefferson County), an area mantled by clayey colluvium is divided into four zones: nonswelling, slight-, moderate-, and high-swelling zones (Hart, 1974; Miller and Bryant, 1976; Noe and Dodson, 1997; Noe and others, 1997). In terms of economic loss to urban infrastructure, swelling soil and heaving bedrock are regarded by some to be the chief geologic hazards in the Front Range urban corridor. Thickness of colluvium is 0.5–2 m

ccm **Andesitic clayey colluvium**—Yellowish-brown, clayey, very fine to very coarse quartz sand in upper few centimeters. Grades downward through 0.1–0.3 m of brown clayey silt to silty clay (includes common feldspar and weathered volcanic-rock sand grains) to varicolored (olive-green, pale-yellow, and light-gray) clay and silty clay, and to weathered, interbedded tuffaceous siltstone, claystone, and calcareous shale, siltstone, andesitic sandstone, and some conglomerate. Map unit includes areas of shale and soft clayey sandstone outcrop that are potentially expansive and corrosive to metal. Unit also includes thin, discontinuous, remnants of clayey

gravel and sand alluvium. Colluvium locally contains rounded pebbles and few cobbles of quartzite, granitic rock, gneiss, and vein quartz. Secondary calcium carbonate commonly forms patchy coatings on clasts. Friable and soft, white veinlets and small masses of pedogenic calcium carbonate are common at a depth of 2–3 m. Colluvium is slowly permeable, calcareous, moderately alkaline, and gypsiferous in places. Generally on moderately steep, eroded land; dissected by ravines near South Platte River. Generally about 1.5–2 m thick

caa **Andesitic loamy colluvium and sheetwash alluvium**—Dark-grayish-brown, olive-brown, and light-yellowish-brown loam, sandy clay loam, and clay. Commonly gravelly at base. The volume of gravel in the colluvium varies locally. Matrix is compact, poorly sorted, clayey and silty, and contains minor very fine to very coarse quartz and lithic sand. Colluvium is very sticky when wet and very hard when dry, and dry colluvium breaks into angular, coarse blocky pieces. Matrix contains soft masses and veins of calcium carbonate, is moderately alkaline, and shrinks and swells with sorption of varying amounts of water. Colluvium interfingers with residuum on summit surfaces and is veneered by loamy, thinly bedded sheetwash alluvium on gentle foot slopes. Map unit includes scattered remnants of pediment gravel (1–3 m thick), composed of subrounded pebbles and cobbles of andesite, granite, gneiss, and schist washed by streams from the Green Mountain Conglomerate and other andesitic, tuffaceous, gravelly sandstone bedrock of Tertiary age. The deposits are chiefly on hillslopes and toe slopes as aprons, dissected pediments, and alluvial fans, and they veneer softer claystone and andesitic and feldspathic sandstone bedrock. The flanks of North and South Table Mountains near the summit cliffs are strewn with latite (a mafic volcanic rock) boulders as much as 2 m in diameter; a rockfall hazard exists there. Also, these slopes are unstable;

hummocky landslide deposits are common, locally abundant. The colluvium contains sparse white, light-gray, and light-olive-brown, tuffaceous lithic sandstone clasts (litharenite). Colluvium grades to pale-yellow-brown, olive-yellow-brown, and grayish-brown, weathered, clayey and silty sandstone and conglomerate. Sand grains are angular, chiefly fine to medium sand but including some coarse grains; grains of quartz and feldspar predominate; minor lithic grains, mica grains, and dark heavy-mineral grains also are present. The colluvium and the underlying weathered sedimentary bedrock are firm to soft; generally easily excavated by earth-moving equipment. Thickness 0.5–5 m

clx **Clay loam colluvium**—Light-yellowish-brown and brownish-yellow clay loam, clay, and silty clay loam containing scattered shale or clayey limestone chips, locally abundant limestone chips, and clusters of selenite (gypsum) crystals < 5 mm in diameter. Locally, the colluvium is micaceous and it contains pebble-size, angular fragments of ironstone concretions and lag gravel of granitoid rock types derived from older alluvial deposits. Strongly calcareous, moderately alkaline. The colluvium erodes easily. Unit may be 20–40 percent shale outcrop where slope gradient is more than 25 percent. Grades downward to interbedded pale-brown and yellowish-gray, fine- to medium-grained sandstone and dark-gray, carbonaceous or lignitic shale 0.5–2 m thick

csk **Grus, crystalline-clast colluvium, rock outcrop, and alluvium**—Surficial detritus, commonly gravelly sandy loam, and bare rock in mountainous areas where bedrock is mostly granite, felsite, granitoid plutonic rock, gneiss, schist, and (or) migmatite. Published bedrock maps show many types of source rock. For example, in Clear Creek County source rocks are chiefly biotite and amphibolite gneiss, locally granodiorite, gabbro, monzonite, and

amphibolite (Sims, 1964). Gravelly sandy loam derived from quartz monzonite covers much of Brewery Hill and Bald Mountain (south Summit County) and Boreas Mountain and Little Baldy Mountain (north Park County). Map unit includes colluvium made of volcanic rock in Clear Creek and Gilpin Counties and biotite gneiss and granodiorite along the continental divide between Gilpin and Grand Counties. Map unit includes grus, colluvium, steep rock outcrop, and local debris-flow deposits, and includes alluvium on foot slopes, on flats, and in drainages. Types of materials vary locally; their proportions in most mapped areas generally are ~20 percent rock outcrop, ~40 percent granitic blocky colluvium, ~30 percent gneissified rock or saprolite, and ~10 percent arkosic sandy, mixed colluvium, debris-flow deposits and alluvium.

Grus is gravelly, sandy detritus produced by in-place disintegration of coarse-grained crystalline rock. Grus typically is brown and very pale orangish brown, fine to very coarse sand that includes granules and pebble-sized angular pieces, individual or aggregated, of quartz, feldspar, biotite, and trace iron-magnesium minerals. Acidic at high elevations; generally alkaline and calcareous below about 2,500 m. Grus locally contains subangular punky rock fragments and unweathered corestones 0.5–3 m in diameter. The distribution of deposits of thick (>10 m) grus is not predictable; the deposits are present on some gently rolling uplands, and are exposed in roadcuts at Pine Junction and south of Indian Hills (in Jefferson County). Blair (1975) noted that depth of weathering (and thickness of grus) derived from crystalline bedrock in the Rampart Range in Colorado generally is 6–30 m on north-facing slopes and 3–4 m on south-facing slopes, and it is concentrated along sets of joints in the bedrock. Grus is easily excavated. Grus thickness generally is 1–10 m; locally, it is as thick as 20 m.

Colluvium of the **csk** map unit is mostly a mixture of sand, granules, and blocks of crystalline rock deposited by gravity on steep (about 30–70 percent; 17°–35°) hillslopes. On moderately steep hillslopes (15–30 percent), generally it is finer grained and has a matrix of brown, micaceous, silty, fine to coarse-grained quartz and lithic sand and granules containing 5–35 percent angular crystalline-rock clasts. On relatively gentle hillslopes (less than 15 percent), colluvium commonly grades laterally to sandy alluvium in fans and aprons. Quartzose silt, 0.5–2 m thick, mantles some toe slopes on fractured crystalline rock. Gravelly, matrix-supported debris-flow deposits occur commonly on steep valley and canyon sides of most major east-flowing streams in the Front Range (James Soule, oral commun., 1999). The matrix of the deposits commonly is silty sand, and clasts range from granules to boulders in random orientation. Debris flows are a significant geologic hazard in the Front Range because they have a consistency of wet concrete, carry large clasts, and can travel large distances (Jeff Coe, written commun., 2000).

Rock outcrop includes ledges, cliffs, and pinnacles of gray, grayish-brown (weathers brownish-yellow), pale-red, reddish-brown, and pink crystalline rock. Rock may contain soil-filled crevices. Intersecting joints, shear zones, layering, and foliation cause the rock to break into blocks and crude rhombohedral pieces, centimeters to several meters across. The tendency to break along planes of weakness allows engineers to predict where block slides, rock falls, and other types of landslides may occur. In lower Turkey Creek Canyon (southwest of Denver and in central Jefferson County) rock sliding (unit **jbc**) has occurred in response to construction of Highway 285. Undercutting of foliation planes in layered granitic gneiss and amphibolite bedrock on steep slopes has caused sliding of rock masses (Miller and Bryant, 1976). Rock

outcrop is common elsewhere in canyons and above timberline but is not distinguished within this map unit. Extensive bare bedrock is mapped with the symbol “R.”

Alluvium in map unit **csk** is gravelly, quartzose and feldspathic sand and silt or sandy, crystalline-rock gravel in stream valleys, on flats, and in small fans. The alluvium on upland meadows and in valleys of tributary streams is too small in area to map separately. Alluvium generally is 1–4 m thick

csm Tuffaceous colluvium—Light-brownish-gray, light-gray, and light-grayish-orange silty clay, clayey silt, clayey fine sand, and tuffaceous, micaceous, feldspathic, quartz sand; locally gravelly and (or) ashy. Grades downward to interbedded tuffaceous or ashy (volcanic), arkosic, and chaledonic siltstone, claystone, sandstone, and conglomerate beds of valley-fill origin composed of granite, quartz-feldspar gneiss, pegmatite, schist, and andesite. Includes pale-brown deposits of sand, silt, and subordinate clay and gravel. Unit may contain swelling clay and thin beds of clayey silt and sandy alluvium. Near mountain fronts, colluvium contains boulders 1–2 m in diameter. Some boulders are dark-gray, greenish-gray, or purplish-gray andesite and trachyandesite derived from volcanic laharic bedrock. In the Vasquez Mountains in the extreme northwest corner of the quadrangle, boulders of granitic and metamorphic rock 1.5–3 m in diameter are present. Crystalline clasts generally present in the colluvium include granodiorite, quartz monzonite, pegmatite, aplite, related granitoid intrusive rocks, and feldspathic gneiss. In the southwest part of the quadrangle, in Park County near Jefferson and Milligan Lakes, prominent cobble-strewn ridges are present. The cobbles are tuff, silicified wood, porphyry, quartzite, chert-pebble conglomerate, and sandstone. Colluvium commonly is 1–3 m thick; less than 1 m thick on moderately steep slopes

cgh Arkose-clast loamy colluvium—Pale-red and reddish-brown, pebbly, sandy

loam and coarse sandy loam colluvium containing 10–35 percent subangular to subround granules, pebbles, and small cobbles of arkose or arkosic sandstone. Near Woodland Park, at the south-central edge of the quadrangle, as many as half of the clasts may be pink, coarse-grained granite (Pikes Peak Granite). In some places, the pebbly sandy loam grades downward to sandy loam that is sticky to slightly sticky and plastic to slightly plastic when wet. The colluvium forms sloping fans and valley slope deposits derived from weathered granite. Cliffs and rounded monolithic outcrops of reddish arkosic sandstone make up 20–40 percent of local areas within the map unit. Colluvium grades downward to, or abruptly overlies, moderate-reddish-brown, iron-stained arkosic alluvium and sandstone. Thickness 0.2–3 m

cgc Gneiss- and granite-clast gravelly colluvium—Brown, very cobbly sandy loam. Pale-red, brown, white, and gray, rounded to subangular pebbles, cobbles, and boulders in a dark-grayish-brown and light-yellowish-brown sandy loam, clay loam, or sandy clay matrix. Locally, the colluvium has a sandy clay matrix that is hard when dry, sticky and plastic when wet. The colluvium commonly contains clay minerals that can exert swelling pressures of more than 2,500 pounds per square foot (Scott, 1972c). Relatively young colluvium has weathered from, and grades downward to, poorly cemented conglomerate, sandstone, and claystone bedrock of Paleocene age that underlies Green Mountain (16 km west-southwest of downtown Denver). The colluvium also has developed on sandy gravel of Tertiary age (Bryant, 1976) that caps some drainage divides in the Front Range and probably was deposited by ancestral Clear and Bear Creeks and by the ancestral North Fork of the South Platte River. Other cgc deposits are mapped near the Jefferson County–Park County line, 11–12 km north of Evergreen (western Jefferson County). In addition to the

predominant gneiss and granite, clasts include quartz, Silver Plume Quartz Monzonite, Pikes Peak Granite (south part of quadrangle), and some porphyry; some boulders are as large as 5 m in diameter. On the upper half of Green Mountain, clasts (listed as most to least abundant) are felsic gneiss, granite, pegmatite, and biotite-quartz-plagioclase schist. Rock types that are less than 10 percent of the clasts include hornblende-plagioclase gneiss, amphibolite, mica schist, white, very hard quartzite and vein quartz, olive-yellow and grayish-brown andesite, porphyritic and aphanitic volcanic rocks, and a trace of red sandstone and conglomerate. On the flanks of the lower half of Green Mountain, clasts are mostly andesite, which disintegrate easily. Small areas of dark-brown, stony, micaceous silty sand residuum are present in 5–20 percent of the mapped area on Green Mountain. This map unit includes scattered landslide deposits, some of which are active (Scott, 1972b). Colluvium is generally less than 1–1.5 m thick; locally, it is 3 m thick at the bases of slopes, in slump-formed depressions, and in fans

cbh Blocky sedimentary-rock colluvium—Grayish-red, moderate-red, reddish-brown, pale-brown, white, and gray blocky loam, clay loam, and silty clay loam derived from sandstone, arkosic sandstone, shale, mudstone, and limestone. Locally, the colluvium includes fragments of silty limestone, anhydrite, and gypsum. In areas of well-cemented, steeply sloping bedrock, more or less continuous rock outcrops make up 10–35 percent, locally as much as 60 percent, of area mapped. Southeast of Fairplay (in the southwest part of quadrangle), unit is mainly pale-red to grayish-pink, blocky sandstone colluvium on the flanks of Red Hill. Locally, the map unit includes small, unmapped deposits of talus, fan alluvium, debris-flow fan deposits, and landslide deposits. Grades downward to, or abruptly overlies, various kinds of sedimentary bedrock. Thickness generally 0.10–1 m on steep slopes

- and 1–3 m elsewhere; in local aprons colluvium is as thick as 10 m
- cbm **Carbonate-clast loamy colluvium**—Brown and grayish-brown, stony loam colluvium containing 35–50 percent pebble- to cobble-size angular and subrounded fragments of gray limestone, dolomite, and minor sandstone and quartzite. Matrix has granular structure, is friable, slightly sticky, and slightly plastic when wet. Grades downward to weathered and fractured bedrock. Map unit locally includes outcrops of limestone, dolomite, and minor sandstone and quartzite. Thickness of colluvium generally less than 0.5 m on steep slopes, 0.5–1.5 m elsewhere
- cbs **Rhyolite- and andesite-clast colluvium**—Bouldery sandy colluvium containing abundant (50 percent or more) angular, granule-, pebble-, cobble- and boulder-size clasts of dark-gray, pink, or white andesitic and rhyolitic volcanic rock. Along Reinecker Ridge, in the southwest corner of the quadrangle, unit includes clasts of tuff, hypabyssal porphyry, andesitic sandstone, breccia, and conglomerate and, near the west edge of quadrangle (northwest Park County), includes monzonite clasts. Colluvium grades downward to volcanic rocks and volcanoclastic sedimentary rocks, including fine-grained and porphyritic tuffs, glassy and brecciated volcanic rocks, feldspathoid-rich, fine-grained rocks in dikes and plugs (phonolite); underlying bedrock locally is laharcic and tuffaceous claystone, siltstone, volcanic sandstone, and (or) arkosic volcanic-clast conglomerate. The composition of clasts in the colluvium may include these kinds of rock in varying proportions. Thickness 2–4 m
- cbu **Mixed-lithology blocky colluvium**—Grayish-brown, light-brownish-gray, and varicolored blocky colluvium characterized by rock clasts mixed in various proportions. The matrix commonly is slightly clayey, cobbly sand. Clasts are chiefly sandstone, hornblende gneiss, schist, granite, and monzonite; locally, clasts are andesitic volcanic rocks derived from lahars and volcanic breccia. Map unit includes landslide deposits, especially where bedrock is shale. Thickness 2–4 m
- xlu **Feldspathic loamy disintegration residuum**—Light-gray and olive-brown sandy silt and clay, clayey sand, and pebbly clayey sand. Clay loam at surface grades downward to weathered, stratified clayey sandstone, sandy claystone, and siltstone. Residuum commonly is micaceous, feldspathic quartz-grain sandy loam on very gently rolling land surfaces. Sparse to common, rounded pebbles of granitic rock, vein quartz, gneiss, schist, and approximately 5 percent maroon and red arkosic sandstone (Fountain Formation) are scattered on the land surface; locally, cobbles and a few boulders are on the surface. In some places the residuum is an expansive soil hazard. During construction of highway E-470 (in west Arapahoe County), engineers determined that surficial materials were so expansive that the subgrade required excavation and replacement with nonexpansive material. This costly remediation work extended from about 5 mi (8 km) southeast of Cherry Creek Reservoir, northward toward Denver International Airport. Included in the map unit are unmapped scattered areas of small eolian sand dunes stabilized by vegetation (unit ed). Locally, near some streams, unit xlu includes scattered, thin terrace deposits of sand and gravel that were mapped by other workers as Slocum Alluvium. Residuum is 1–2 m thick
- xlv **Loamy disintegration residuum, eolian sand, and sheetwash alluvium**—Pale-brown, very pale brown, light-yellowish-brown, and light-gray loam, sandy loam, and loamy sand. Surficial materials cover upland slopes that are less than about 5 percent. Locally, the materials are slightly dissected by drainageways. The deposits generally are alkaline and highly calcareous; locally, the sediments contain calcium carbonate splotches and veinlets. Hard when dry, friable when moist. Locally contains gravel size clasts. Grades

downward to interbedded fine- to medium-grained sandstone and dark-gray carbonaceous shale. Map unit locally includes areas of stream alluvium and reworked wind deposits. Mapped in northeast corner of quadrangle. Thickness generally is more than 2 m, locally 4 m

xsa **Feldspathic quartz-sand disintegration residuum**—Pale-yellow, white, very light gray, and medium-gray, coarse-grained sand containing scattered yellowish-gray and grayish-orange-pink sandstone pebbles, cobbles, and boulders. Within mapped areas there are conglomeratic sandstone ledges from which fall blocks that are 0.3–3 m in diameter. Upper 5–15 cm of residuum is pinkish-gray, feldspathic and granitic, coarse sand. On nearly level land, at a depth of 0.2–0.4 m, the residuum is dark-yellowish-brown clayey sand or loam (B soil horizon) that grades downward to brown clayey, pebbly *grus*. In some places the *grus* layer grades laterally to a thin lag of pebbles and cobbles on sandy claystone bedrock. In other places, the residuum grades downward to sandy claystone and clayey sandstone and firm to poorly cemented feldspathic sandstone. Within the areas mapped as **xsa** there are some hills (8–15 percent slopes), especially in southern Arapahoe County, and small buttes that are thinly covered by intermixed colluvium, sheetwash alluvium, and residuum. Scattered throughout the mapped area are outcrops of poorly cemented conglomerate bedrock, which produce colluvium composed of abundant cobbles and small boulders of granite, bluish-gray quartzite, sandstone, gneiss, volcanic tuff, and petrified wood. Unit **cac**, arkosic colluvium and sheetwash alluvium on hilly land, is compositionally similar to unit **xsa**, and areas of the colluvium are included in the map unit. A lag deposit of granitic cobbles is present in some places. Sandy alluvial fan deposits and sheetwash alluvium are on toe slopes. Pieces of red and brown silicified wood, 0.1–1 m long,

are locally common on the surface. Residuum is 0.5–2 m thick

xgb **Latite-clast disintegration residuum**—Dark-gray, brownish-gray, grayish-brown, and yellowish-brown, subrounded granules, pebbles, cobbles, and scattered boulders of mafic latite in a poorly sorted sand, silt, and clay matrix. The residuum is on dark-gray, porphyritic latite caprock of South Table Mountain and North Table Mountain near Golden, in Jefferson County. This residuum generally is of two types (intermediate types occur locally): (1) noncalcareous, gravelly or stony loam and sandy loam and (2) calcareous, clay and clay loam; hard when dry, sticky when wet. The residuum contains sand grains of volcanic rock, quartz, and mafic minerals. Pedogenic carbonate discontinuously coats clasts and is present as thin seams and soft masses at depths of 30–50 cm. In some areas, few or no stones are present in the upper 1–1.5 m; the clayey silt and sand in that part of the material may be eolian sediment and (or) sheetwash alluvium. The residuum contains little or no swelling clay. Latite caprock crops out as cliffs at the margins of the gently undulating surfaces of both North and South Table Mountain. A rockfall hazard is present below the cliffs. Vertical joints in the caprock are filled with brown lithic sand and granules. Thin (0.1–0.2 m) deposits of brown sand and silt and angular pebbles and granules of latite veneer the smooth tops of the caprock. Residuum generally is 0.1–2 m thick

Holocene to Middle Pleistocene

jbc **Bouldery crystalline-rock landslide deposit**—Bouldery and rubbly landslide deposits, including some sand and silt, mainly in mountainous areas underlain by igneous and metamorphic rocks. Thickness 2–8 m

xsg **Feldspathic quartz-sand disintegration residuum**—Pale-brown, light-yellowish-brown, and brown, feldspathic quartz sand and pebbles; more gravelly and feldspar-rich in or near the mountains. Less than 10 percent granules and pebbles of

granite and arkose. The residuum mantles a gently undulating upland surface. The parent material is high-level pediment alluvium and fan alluvium (the Nussbaum alluvium of Gilbert, 1897), of probable late Tertiary to early Quaternary age. Grain size of the residuum varies: typically very fine to very coarse sand, predominantly medium sand. The composition varies from feldspathic quartz to more than 95 percent quartz; in places the sand includes minor limestone or feldspar. Near the mountains the residuum includes small granitic pebbles. On the plains generally it contains about 25 percent granules of olive-colored shale. Contains pebble-size fragments of fossil wood locally. Thickness generally 2–4 m, locally 6 m

LATE PLEISTOCENE

elb

Loess (Peoria Formation)—Moderate-yellowish-brown, pale-brown, and olive-gray wind-blown sandy silt, clayey silt, or clayey fine sand. Particles are predominantly quartz, potassium-feldspar, plagioclase, calcite, and dolomite. Silt, probably derived from glaciofluvial sediment on floodplains of the ancestral South Platte River and its tributaries, from eolian deposits, and from deflation of bedrock sources, was blown onto upland surfaces. Presumably, glacial meltwater in the South Platte River valley contributed a voluminous silt load to the Colorado Piedmont. The silt was derived from rock flour that was scoured from bedrock in the high mountains by glaciers. Volcaniclastic silt and clay eroded from bedrock in the Colorado Piedmont may have provided some of the loess. In northeastern Colorado (between lat 39° and 41° N. and between long 105° and 102° W.), the mean particle size of about 100 grain-size analyses is fine sand (0.20 mm) to silt (0.02 mm) (Muhs and others, 1999). The loess is 60 percent or more silt. It is slightly to strongly calcareous, and it contains calcium carbonate spots, nodules, and veinlets to depths of 1–1.5 m; locally, it may contain lenses of sand and small pebbles. In some

places the loess contains significant amounts of clay and silty clay. Typically, the loess is nonstratified, friable, and weakly compact, and it stands in nearly vertical faces in exposures several meters high; it has blocky or columnar structure and vertical joints. Vertical permeability is moderate, and lateral permeability is very low. Loess is hard when dry, nonsticky to slightly sticky when wet. Subject to wind erosion; includes deflation (blowout) basins. Some deflation basins are occupied by lakes, for example, Bowles Lake (not mapped), southwest of Denver. Previous workers have documented a relict soil on the loess. Malde (1955, p. 242) described a 2-m-thick soil of Wisconsin age developed on an eolian silt and sand unit (which we mapped as **elb**) 1 km northwest of Louisville. He interpreted the soil to be possibly equivalent to the mid-Wisconsin soil of Nebraska and Kansas. A relict soil on the loess west and south of Littleton was described by Scott (1962, p. L29) as a strong Brown soil of mid-Wisconsin age, having distinct prismatic or columnar structure (a similar soil is developed on Louviers Alluvium). Scott considered the loess to be of early Wisconsin age. Machette (1977) interpreted that the loess was deposited during late Bull Lake age and during the following warmer, interglacial period prior to the Pinedale glaciation. Loess covers gently undulating uplands and many old alluvial deposits (**ags**, **agm**), and it thins downwind (east and southeast) from river valleys and eolian sand deposits (**es**). Where the deposit thinly covers the Denver and Dawson Formations (bedrock), excavations may encounter expansive clayey materials (for example, along Highway C–470 east of Chatfield Reservoir, in northernmost Douglas County). In many areas, loess grades laterally to eolian sand, sheetwash alluvium, colluvium, and (or) residuum. Where minor streams have cut through loess, the map unit includes areas of unmapped colluvium (units **cac** or **caa**). The

map unit also includes unmapped small areas of intensely weathered upland gravel, stony and clayey colluvium, and outcrops of shale and sandstone. Thickness of loess varies considerably in the quadrangle. Generally, it is less than 3 m thick; it is entirely eroded adjacent to some drainageways. In the Louisville area, loess is 0.6–4 m thick; south of Commerce City it is as thick as 6–7 m

LATE AND MIDDLE PLEISTOCENE

Bouldery till (till of the Pinedale and Bull Lake glaciations)—Generally a nonsorted, nonstratified mixture of subangular and subrounded boulders, cobbles, pebbles, and granules in a sandy matrix. The relative abundance of pebbles, cobbles, or boulders varies; however, boulders typically are conspicuously present and commonly are abundant. Some boulders are larger than 5 m in diameter. Locally, till is overlain by unmapped, thin loess and the map units (tbg, tbj) include subordinate stratified glaciofluvial deposits near the lower altitude limits of glacial deposits.

Till of Pinedale age (the younger till) is characterized by well-preserved end moraines and lateral moraines and is mantled by unweathered to slightly weathered surface boulders. Weakly developed soil profiles in the till are characterized by 10- to 40-cm thick B horizons containing 1–7 percent more clay than is present in unweathered till. Pedogenic calcium carbonate horizons 40–80 cm thick (stage I carbonate morphology) are common in semi-arid areas. Few clasts are weathered to grus.

Till of Bull Lake age generally forms slightly subdued end and lateral moraines that have broadened and rounded crests. Surface boulders are moderately weathered and pitted, and soil profiles typically are characterized by 35- to 75-cm-thick B horizons that contain 5–13 percent more clay than is present in unweathered till. Pedogenic carbonate horizons 60–100 cm thick, having stage II carbonate morphology of

Gile and others (1966), are common in semiarid areas (Shroba and Birkeland, 1984). Granitic clasts in the B and C horizons of soil developed in till of Bull Lake age commonly are altered to grus.

Maximum early Pinedale glaciation near Winter Park, in the Fraser River valley in the northwest corner of the Denver 1° × 2° quadrangle, occurred later than 30,480±2800/–4300 radiocarbon years before present (¹⁴C yr B.P.) (DIC–482) and later than 30,050±1200 (¹⁴C yr B.P.) (SI–2912) (Millington, 1977; Nelson and others, 1979; Madole, 1986). An early Pinedale mountain glacier in the North Boulder Creek valley dammed a lake in the Caribou Creek valley on the north boundary of the Denver quadrangle, west of Highway 72 and northwest of Nederland. The lake was dammed by a lateral moraine 2.3 km upvalley from the terminal moraine across the North Boulder Creek valley, and formation of the lake was approximately synchronous with maximum early Pinedale glaciation. Basal sediments from Lake Devlin yielded ages of 22,400±1070/–1230 ¹⁴C yr B.P. (DIC–870), 22,040±740/–820 ¹⁴C yr B.P. (DIC–871), and 21,640±610/–650 ¹⁴C yr B.P. (DIC–869). Farther north, in the North St. Vrain valley northeast of Allens Park, till of Bull Lake age yielded a uranium-trend age of 130,000±80,000 yr, and colluvium overlying till of pre-Bull Lake age yielded a uranium-trend age of 220,000±70,000 yr (Madole and Shroba, 1979; Rosholt and others, 1985). The till probably is 1–5 m thick in most places, but it may be 30 m thick in lateral moraines and end moraines

tbg **Crystalline-clast bouldery till**—Light-gray to grayish-brown till having a micaceous, sandy, and grus-rich matrix (sand generally 55–70 percent of matrix). Abundant clasts are subangular to subround and composed chiefly of granite, granitoid rock, gneiss, or migmatite

tbj **Mixed-lithology-clast bouldery till**—Clasts include granitoid rocks, gneiss, migmatite, and sedimentary rocks.

ggq

Outwash sand and gravel (outwash of Bull Lake, Pinedale, and post-Pinedale ages)—Stratified sand and gravel deposited in valleys by flowing, glacial meltwater. Mapped downvalley from till (units tbg, tbj, and tbk) and in glaciated valleys. The outwash deposits generally underlie uniformly sloping (4–10 percent) terrace surfaces 3–10 m higher than adjacent stream channels cut in Holocene time. Extensively dredged for placer gold at Fairplay, along Tarryall Creek (northwest Park County), and along Swan River (west edge of map area, south Summit County). Includes some nonglacial alluvium. Outwash may be present farther downstream than shown on the map; the boundary between outwash and nonglacial alluvium is arbitrary in some valleys. Sandy gravel to gravelly sand having rounded to subangular clasts that grade upvalley into glaciofluvial deposits and till. Grain size, thickness, and particle composition vary widely among small areas. These properties reflect the distance from source glaciers and the variable types of source rocks. Thus, it was impracticable to map compositional subtypes of outwash in the quadrangle. For example, outwash in one watershed at the northwest end of South Park is red and light-gray, calcareous gravelly loam composed of granules, pebbles, and cobbles of arkosic sandstone, pale-green felsic porphyry, hypabyssal rocks, undifferentiated volcanic rocks, and minor flaggy, laminated siltstone. Outwash in an adjacent watershed at the northwest end of South Park is chiefly light-gray, sandy, clast-supported felsic and granitic pebbles and cobbles, and scarce fine-grained, igneous rock, scarce vein quartz, schist, and medium-gray microcrystalline limestone. Thickness 2–8 m

ags

Alluvial sand, silt, clay, and gravel

(Louviers and Slocum Alluviums, undivided; late middle Pleistocene)—Louviers Alluvium near Parker is ~11 m of stratified, pebbly, coarse sand; in paleochannels it contains lenses of pebbles, cobbles, and boulders (Scott and Lindvall, 1970). The upper 1–2 m is yellowish-brown and brown silty sand; much or most of the silt may be loess. Locally, the matrix is light-reddish-brown clayey sand and sandy clay and is streaked or mottled with limonite and manganese oxides. A relict soil commonly is developed in the upper meter of the alluvium. The soil has a clay-enriched B soil horizon that may overlie a carbonate-enriched Cca horizon; in places no Cca horizon is present. The soil is interpreted to have developed after the Bull Lake glaciation (Machette, 1977). The alluvium contains pieces of opalized wood. Clasts are mostly quartz, and minor feldspar. Plane bedded and torrentially crossbedded. Contains fossil bones, a horn core of a giant bison was excavated at a site. Between Turkey and Deer Creeks, in south-central Jefferson County, and at the mountain front the deposit is silty, clayey sand and minor gravel, 2–15 m thick.

Slocum Alluvium (the older of the two alluviums) is yellowish-red, well-stratified gravel that contains granules, pebbles, cobbles, and boulders, generally in lenses. Generally more bouldery near the mountains. Large deposits mapped 25 km southwest of downtown Denver, on the east foothills of the Front Range, are moderate-reddish-brown to brown, silty, clayey coarse sand and granules. These deposits are as thick as 13 m south of Deer Creek (Bryant and others, 1973). Clasts are predominantly granitic rocks; some are pegmatitic, metamorphic, volcanic, and sedimentary rocks derived, in part, from older alluvium (agm). Sand is mostly quartz, feldspar, mica, and magnetite. A skull of *Bison latifrons* was excavated in Slocum Alluvium near Cañon City (60 km south of this quadrangle).

Lumps and layers of olive-gray shale eroded from the underlying bedrock are common locally in the alluvium. Bedding is cross-stratified and planar, and it contains cut-and-fill structures. The lower part of the alluvium locally is thick, poorly sorted gravel overlain by 1–1.5 m of very pale brown, pale-brown, and mottled-white pebbly sand and silt that is slightly sticky and plastic when wet and hard when dry. The alluvium is slightly cemented by clay throughout (except in lower gravelly part) and by calcium carbonate in the upper part where stones have thin, continuous to discontinuous coatings of calcium carbonate. In the upper 1–1.5 m of the alluvium, a thick, reddish-brown clayey B horizon and an underlying white Cca (carbonate-rich) horizon accumulated during an extended period of weathering and deposition of loess. In some places these horizons are eroded. Deposit commonly underlies two terrace surfaces about 36 and 55 m above modern streams. Generally, unit is 3–7 m thick near the mountains (Scott and Lindvall, 1970); 1–2 m thick more than about 15 km away from the mountains. Locally, the deposit is degraded to a lag that mantles an uneven, stream-dissected surface. The lag deposit is grayish-red quartz and feldspar sand and silty clay containing zones of bouldery gravel (Maberry and Lindvall, 1972)

MIDDLE AND EARLY PLEISTOCENE

tbk **Bouldery till (till of pre-Bull Lake glaciations)**—Generally a nonsorted, nonstratified mixture of subangular and subrounded boulders, cobbles, pebbles, and granules in a loamy sand to sandy loam matrix. In some places cobbles are the predominant clast size. Clasts in the upper Fraser River Valley (northwest corner of quadrangle) are quartz monzonite, gneiss, amphibolite, and minor rhyolitic tuff. This till generally is preserved in a few locations downvalley from the younger tills of Bull Lake and Pinedale ages. A thin layer of unmapped loess commonly overlies the till. May include minor

amounts of stratified drift, especially at the lowest elevations of occurrence of the till. Generally lacks constructional morainal form. Surface boulders are deeply weathered and pitted. Many subsurface clasts are altered to *grus*. Soil profile commonly has 1-m-thick B horizon containing three or more times the clay content of unweathered till. In semiarid areas, pedogenic carbonate horizons having stage III or higher carbonate morphology (Gile and others, 1966) are common. The till mapped may have been deposited during more than one glaciation

gge **Outwash sand and gravel (outwash of pre-Bull Lake glaciations)**—Stratified sand and gravel deposited by glacial meltwater. Mapped downvalley from till (tbk). Generally poorly to moderately sorted, sandy pebble and cobble gravel consisting of subrounded and rounded clasts. Texture is stony sandy loam and very stony fine sandy loam. The relative proportions of granules, pebbles, cobbles, and boulders, the kinds of clasts, and the thickness of the outwash from place to place all vary and reflect both the distance from the source glacier and the types of bedrock. Clasts are mostly quartz monzonite, gneiss, amphibolite, and minor rhyolitic tuff in the upper Fraser River Valley (northwest corner of map area). Many subsurface clasts are intensely weathered. Soil profile commonly has 1-m-thick B horizon containing three or more times the clay content of unweathered outwash. In semiarid areas, pedogenic carbonate horizons having stage III or higher carbonate morphology (Gile and others, 1966) are common. The outwash locally contains Lava Creek B volcanic ash (0.62 Ma; Izett and Wilcox, 1982). Unmapped loamy alluvium, colluvium, or loess deposits 0.5–2 m thick overlie the outwash in places. The outwash forms terraces 80–400 m above modern stream levels. Less than 1 m thick on eroded terrace surfaces; at least 3 m thick elsewhere

agm Alluvial gravel and sand (Verdos and Rocky Flats Alluviums, undivided; early middle and early Pleistocene)—Poorly sorted, intensely weathered, matrix-supported and clast-supported, subangular and subrounded cobble and pebble gravel containing a sand and clayey sand matrix; bouldery in pediment and fan deposits near mountains and in fluvial terrace deposits of the South Platte River. Grain size decreases eastward from the mountains. The matrix is light-brown and light-red, oxidized clayey sand, sandy clay, and a mix of sand, silt, and clay in various proportions that is marked by intense accumulation of calcium carbonate in many places. Includes lenses and beds of pebble gravel, pebbly silty sand, and gravelly clay. Pedogenic clay thickly coats sand grains and clasts. Occurs as high-level fluvial deposits on old erosion surfaces (pediments) at the eastern foot of the Front Range, at two isolated locations on the plains, and in Woodland Park (north Teller County). Clasts are mostly granite, gneiss, sandstone, quartzite, and minor vein quartz, pegmatite, and schist; locally, claystone pebbles are present at the base. Clasts of granitoid plutonic rocks and gneiss crumble easily, are coated with secondary clay and calcium carbonate, and are not suitable for concrete aggregate but are used locally for road material. Pebble counts on Rocky Flats (25 km northwest of the State Capitol) indicate that 60–77 percent of clasts are very hard, subangular metaquartzite clasts derived from the Coal Creek Canyon area (Boos and Boos, 1934; Shroba and Carrara, 1996); these clasts make excellent aggregate. The Verdos Alluvium, the younger part of the agm unit, contains the 0.62-Ma Lava Creek B volcanic ash in some places (Izett and Wilcox, 1982). A relict soil is present in the top 2 m of the agm unit owing to protracted weathering of alluvium. The soil contains a reddish, clay-enriched B soil horizon, which overlies a pedogenic calcium

carbonate-enriched zone 0.6–1.2 m thick (in places forming a laminar K soil horizon). Abundant white calcium carbonate fills vertical joints and is concentrated laterally along contacts between gravel and sand lenses (Malde, 1955); most clasts have carbonate rinds. Alluvium on high, east-sloping surfaces at the east margin of the Front Range is attributed to pediment processes (see, for example, Tator, 1952; Scott, 1960). The alluvium includes debris-flow deposits.

Rocky Flats Alluvium, which has weathered longer than the Verdos Alluvium, is generally redder in color (reddish-brown, light-brown, and light-red) and more clayey than the Verdos Alluvium. Various workers describe the prevalent grain size of the Rocky Flats Alluvium as sandy gravel; slightly bouldery, cobble and pebble gravel that contains a clayey sand matrix; sandy pebble gravel, pebbly silty sand, and cobbly to pebbly sandy clay. Clasts are largest near the mountains and decrease in size eastward. The alluvium forms a large fanlike deposit at Rocky Flats (lat 39°52' N., long 105°15' W.). This alluvium is generally about 45–70 m higher than modern streams, locally as much as 90 m. At Rocky Flats, the alluvium commonly is 1–10 m thick, and locally it is > 30 m thick (Shroba and Carrara, 1996). It includes thick channel-fill deposits of gravel (Madole, 1991). Near the mountain front, it contains boulders as large as 6 m across. Locally present are beds and lenses of cobbly and silty clay of probable debris-flow origin. At the east limit of Rocky Flats the average pebble diameter is 1 in. (Malde, 1955). Elsewhere in the quadrangle, the agm deposit is estimated to be 3–6 m thick

PLEISTOCENE

pga Pediment gravel—Gray, bouldery alluvium composed mostly of andesite clasts in pediment remnants on flanks of mountains. Poorly sorted and crudely stratified. Map unit includes minor areas of reddish-brown, fairly well stratified and sorted sand and pebbles,

cobbles, and boulders composed of sandstone, limestone, and locally, gneiss and granodiorite. An intensely developed calcium carbonate-enriched soil is present in the upper part of the alluvium. The alluvium forms a broad terrace or gently sloping alluvial surface (several kilometers wide and long) about 25 m above the valley bottom in South Park (southwest part of quadrangle). Thickness is about 6 m

QUATERNARY

cra Hogback and rangefront colluvium, alluvium, and rock outcrop complex—Two or three rocky ridges (hogbacks) and intervening valleys, eroded from steeply dipping sedimentary rocks of variable composition and grain size along the steep east front of the Front Range. Moderately steep to very steep (15–100 percent slopes), wooded bedrock ridges and associated colluvial and alluvial deposits extend north-south in compositionally different strips, too narrow to differentiate on this map. The deposits and rock outcrop complex are mapped as a single unit. Thick intervals of resistant arkosic sandstone, quartzose sandstone, and minor tuffaceous sandstone, conglomerate, and thin intervals of limestone (and an exceptional mafic latite ridge, the Ralston Dike, north of Golden) underlie and crop out along the ridges. The ridges are mantled by blocky and gravelly sandstone colluvium, 1–8 m thick, that varies in texture (sand, silty gravelly sand, silty clayey sand, and other grain-size mixtures) (Miller and Bryant, 1976). The colluvium contains fragments of bedrock as large as several meters in diameter; and it locally includes slump deposits and talus. Valleys between hogbacks are eroded into softer rocks, mostly shale and mudstone, that locally are interbedded with thin sandstone beds or layers of concretions. Colors and the mineral composition of the deposits vary, determined mainly by the varied colors and composition of the source rocks. Feldspar-rich sedimentary bedrock that contains

iron-rich accessory minerals (for example, the Fountain Formation) tends to produce light-reddish-brown to grayish-red, blocky, sandy loam colluvium. More quartz-rich sandstone commonly produces a humus-rich, grayish-brown and light-reddish-brown, blocky, sandy loam colluvium. Shale or mudstone in low, gently sloping areas produce grayish-brown, clayey or silty colluvium, patchy alluvium, and small areas of grayish-brown clayey residuum. The residuum is discontinuously covered by residual gravel of granite and gneiss. Gentle slopes are veneered by alluvial aprons of pebbly sand, very fine sand, and silty sandy clay, which locally contain shale and limestone chips.

Pediment gravel remnants at the base of the abrupt east face of the Front Range are included in unit **cra**. The granitic gravel covers gently east-sloping, planar, erosion surfaces (pediments) on many divides between modern streams; the surfaces generally are 30–100 m above the streams. The deposits are similar to those described as units **agm** and **ags**, but they are too small to map at this scale. They are 2–6 m thick and 10–200 m in width. Floods and debris flows deposited this material in early and middle Quaternary time.

Piney Creek Alluvium (Holocene), generally 2–8 m thick, is in channels and beneath floodplains of modern streams that follow the strike of inclined shale and mudstone bedrock units. Clasts in the alluvium are chiefly granite and sandstone. Grain size is variable and includes gravel, clayey fine to coarse sand, silt, and clay. The alluvium commonly has a dark-grayish-brown humic A soil horizon, 0.3–0.5 m thick, in its upper part. It grades laterally to colluvium, shaley debris-apron deposits, and talus

EARLY PLEISTOCENE AND PLIOCENE?

QTdd Diamicton—Till-like, gravelly deposits along the South Boulder Creek–Boulder Creek divide near the north

boundary of the Denver quadrangle, between Pinecliff and Nederland (Boulder County). Deposits are present above 2,500 m (8,200 ft) elevation. They are similar to deposits on Niwot Ridge, a 2-km-long landform in alpine tundra about 10 km north of the quadrangle. Madole (1982) concluded that no single geologic process could convincingly account for the deposits (thus, the nongenetic name “diamicton”), but that they may be mixtures of mostly alluvium and colluvium. Previous workers have interpreted such deposits as till. Deeply weathered, roughly round to angular boulders are scattered on the surface; most boulders are 0.25–0.5 m in diameter. Composed of boulders of exotic rock in a poorly sorted matrix, chiefly coarse to very coarse sand, on monzonite and other igneous rock types on rounded interfluvial ridges and cols. The diamicton deposit is older than local tills and similar to them texturally, but it lacks morainal form. Thickness unknown; base concealed. Estimated thickness of 3–35 m interpreted from seismic methods for the deposit on Niwot Ridge (Madole, 1982). At edges, deposit thins to 1–2 m, imperceptibly grading into talus and colluvium

PRE-QUATERNARY

- R **Bedrock**—Various types of bedrock having no cover of detritus except for minor gravel and thin soil in scattered pockets and crevices. Includes areas of alpine tundra too small to map. Mostly precipitous peaks, cliffs, knife-edge divides (aretes), cols, cirque walls that include some talus, and steep canyon walls. Rockfall hazard exists in canyons

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