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Geologic Map of the Bailey 30′ × 60′ Quadrangle, North-Central Colorado

By Chester A. Ruleman, Robert G. Bohannon, Bruce Bryant, Ralph R. Shroba, and Wayne R. Premo

Pamphlet to accompany
Scientific Investigations Map 3156

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Divisions of the Cenozoic, Mesozoic, Paleozoic, and Proterozoic eras used in this report.

Era	Period or Subperiod	Epoch		Age
CENOZOIC	Quaternary	Holocene		0–11.5 ka
		Pleistocene	late	11.6 –132 ka
			middle	133–788 ka
			early	789 ka–1.81 Ma
	Neogene	Pliocene		1.82–5.33 Ma
		Miocene		5.34–23.0 Ma
	Paleogene	Oligocene		23.1–33.9 Ma
		Eocene		34.0–55.8 Ma
		Paleocene		55.9–65.5 Ma
MESOZOIC	Cretaceous	Late		65.6–99.6 Ma
		Early		99.7–145.5 Ma
	Jurassic	Late		145.6–161.2 Ma
		Middle		161.3–175.6 Ma
		Early		175.7–199.6 Ma
	Triassic	Late		199.7–228.0 Ma
		Middle		228.1–245.0 Ma
		Early		245.1–251.0 Ma
PALEOZOIC	Permian	Lopingian		251.1–260.4 Ma
		Guadalupian		260.5–270.6
		Cisuralian		270.7–299.0 Ma
	Pennsylvanian	Upper/Late		299.1–306.5 Ma
		Middle		306.6–311.7 Ma
		Lower/Early		311.8–318.1 Ma
	Mississippian			318.2–359.2 Ma
	Devonian			359.3–416.0 Ma
	Silurian			416.1–443.7 Ma (Absent in map area)
	Ordovician			443.8–488.3 Ma
	Cambrian			488.4–542.0 Ma
NEOPROTEROZOIC				542.1 –1000.0 Ma
MESOPROTEROZOIC				1000.0–1600.0 Ma
PALEOPROTEROZOIC				1600.0–2500.0 Ma

Ages of time boundaries are those of the U.S. Geological Survey Geologic Names Committee (2007) except those for the late-middle Pleistocene boundary and middle-early Pleistocene boundary, which are those of Richmond and Fullerton (1986a). Ages are expressed in ka for kilo-annum (thousand years) and Ma for mega-annum (million years).

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Description of Map Units

Surficial Deposits

Descriptions of surficial units along the eastern flank of the Front Range on this map are based on those of Scott (1963a), Trimble and Machette (1979), and Kellogg and others (2008). Within South Park, distribution and description of surficial units were derived from reports by Stark and others (1949), Widmann and others (2005), Kirkham and others (2006), and the authors' new mapping and field observations. Formal names for fluvial and pediment deposits are those established by Scott (1960, 1963a) in the Colorado Piedmont. South Park glacial, glaciofluvial, and alluvial deposits are based on inferred age relationships among geomorphic position in the landscape, soil development, and reports by Widmann and others (2005, 2006), and Kirkham and others (2006).

Surficial units were mapped primarily by interpretation of 1:40,000-scale, black-and-white aerial photographs, USGS black-and-white digital ortho-photoquads (1-meter resolution), Landsat Thematic Mapper images, and field analyses of deposits and landforms. Age assignments for surficial deposits within the map area are based chiefly on the relative degree of modification of their original surface morphology, relative heights above present stream channels, and degree of soil development and clast weathering. Soil-horizon designations are based on those of the Soil Survey Staff (1999) and Birkeland (1999). Some of the surficial deposits contain pedogenic calcium carbonate. Stages of pedogenic calcium carbonate morphology (referred to as stages I through IV) in Bk and K soil horizons follow the classification from Gile and others (1966) and Machette (1985).

Grain sizes within unit descriptions follow those of the Soil Survey Staff (1951) and are as follows: sand (0.05–2 mm), silt (0.002–0.05 mm), and clay (<0.002 mm). Grain sizes are limited to field estimates. The term "clasts" is defined as granules and larger particles (>2 mm in diameter, visible without magnification), and the term "matrix" refers to sand and finer particles (≤ 2 mm in diameter).

Many of the surficial deposits are poorly exposed. Deposits that are of limited extent (commonly less than about 50 m wide) were not mapped, including 1) fill material in developed areas, 2) mine-and-mill waste and dredge tailings in mining areas, 3) thin mass-movement deposits above treeline (such as block fields and block streams), and 4) thin sheetwash deposits that locally mantle gently sloping map units.

In addition to the relative age of deposits based on erosional, geomorphic, and weathering characteristics, we have inferred ages for some of the surficial units based on the marine oxygen isotope records of Lisiecki and Raymo (2005). These records reflect global ice volumes (for example, Shackleton and Opdyke, 1973, 1976). However, ice volume changes on continents may supercede oxygen isotope variation in marine cores by 500–3,000 years (Mix and Ruddiman, 1984).

Artificial-Fill Deposits

mw **Mine waste (latest Holocene)**—Unconsolidated to loosely compacted rubble composed of silt, sand, rock, waste rock, and locally deeply weathered mining equipment derived from mining operations in the Alma district. Angular rock fragments are primarily composed of a mixture of altered Proterozoic igneous and metamorphic rocks and Tertiary igneous rocks. Estimated thickness several meters to 10 m

Alluvial Deposits

Qa **Post-Piney Creek alluvium and Piney Creek Alluvium, undivided and youngest alluvium in mountain valleys and South Park (Holocene and late Pleistocene?)**—Interbedded silt, sand, and gravel along major streams, tributaries, and washes. Unit is commonly coarser grained and cobbly proximal to source areas and mountain-piedmont junctions. Post-Piney Creek alluvium commonly lies within stream channels inset into Piney Creek Alluvium and consists primarily of silty to sandy overbank deposits and slightly coarser, pebbly sand channel deposits. Soils on post-Piney Creek alluvium commonly are very weakly developed and have A/Cu profiles. Piney Creek Alluvium commonly consists of sandy silt, silty sand, lenses of silty clay, and detrital organic matter in upper part, and mostly sand and lenses of pebble gravel in lower part. Unit forms one or two terraces less than 5 m above present streams, and locally forms alluvial fans and sheetwash aprons along margins of major valleys. Soils on Piney Creek Alluvium are slightly better developed. They commonly have A/Bw/C profiles and locally may contain weak stage I carbonate morphology. Piney Creek Alluvium forms much of the present floodplains with post-Piney Creek alluvium being the younger inset deposits that are more susceptible to seasonal flooding.

Charcoal collected from an archeological site in Piney Creek Alluvium near Kassler, Colo. yielded an age of about 1,500 14C yr B.P. (carbon-14 years before present; Scott, 1962, 1963a). Radiocarbon ages of organic material in Piney Creek Alluvium near Colorado Springs range from about 1.1 to 2.2 ka (Madole and others, 2005). Unit may locally contain pre-Piney Creek alluvium (Scott, 1960, 1962, 1963a). Thickness about 1–6 m

Qay **Young alluvium (late Pleistocene)**—Beds and lenses of silt, sand, and pebble- to cobble-sized gravel deposited chiefly during Pinedale glaciation [oxygen isotope stage 2, 14-24 ka, (Lisiecki and Raymo, 2005]. Within South Park near the Mosquito Range, unit consists of glacial outwash composed chiefly of cobbly pebble gravel that underlies terraces less than 5 m above floodplains in major mountain valleys near and below the outer limit of glaciation. Unit may also contain younger alluvial fan and sheetwash deposits grading to top of unit. Depositional surface of deposits has well-expressed bar-and-swale morphology with less than 1 m of relief. Gravel clasts are subrounded to well rounded and are well sorted. Soils formed in top of unit have thin (<20 cm) Bt horizons and commonly have A/Bw/C profiles. Locally they have Bk horizons with stage I to weak stage II carbonate morphology. Top of unit Qay is commonly inset into units Qao and Qai as much as 15 m below top of units Qai and Qao. Maximum thickness <10 m

Qai **Intermediate alluvium (late middle? Pleistocene)**—Moderately sorted to well-sorted sandy pebble-sized gravel and, locally, cobbly to bouldery gravels deposited during Bull Lake glaciation, which occurred about 120–170 ka (Schildgen and others, 2002; Sharp and others, 2003;

Pierce, 2004) [marine oxygen isotope stage 6, 130–150 ka (Lisiecki and Raymo, 2005)]. In South Park, Qai underlies outwash terraces grading to Bull Lake moraine complexes. Terraces are as much as 15 m above present stream channels. Terrace treads have a smooth surface commonly underlain by eolian silt of variable thickness. Unit Qai also includes alluvium of non-glacial origin. Soils formed in this unit commonly have a Bt horizon with blocky to prismatic structure and reddish hues. Pedogenic Bk horizons with stage II to III morphology are locally present. Thickness 3–10 m

Qs **Slocum Alluvium (middle Pleistocene)**—Mapped only in northeast corner of quadrangle. Well-stratified, carbonate-cemented, pebbly to cobbly gravels and coarse sand fining to east of mountain front. Upper part of unit commonly consists of about 1-m-thick silty clay and probably is of eolian origin (Scott, 1963a). Clasts are deeply weathered and easily broken. Unit primarily consists of pediment and cut-and-fill terrace deposits about 20–30 m above floodplains. Madole (1991) assigned an age of 240 ka, based on a uranium-series age of 190 ± 50 ka near Canon City, Colo.; however, deposits of unit Qs may be as old as about 390 ka (Kellogg and others, 2008, table 1). Thickness commonly less than 8 m

Qv **Verdos Alluvium (middle Pleistocene)**—Unit consists of two parts. Lower part is a well-stratified, boulder-to-pebble gravel grading upward into a coarse sand, with pebbles and cobbles; boulders are more common near Front Range mountain front. Planar cross-stratification is dominant bedform representing sheetflood deposits and deposition of sand as flow regimes waned (Scott, 1963a). Unit contains a silty clay cap up to 1 m in thickness of probable eolian origin (Reheis, 1980). Soils formed in upper part of unit have A/Bt/Bk/K/Bk profiles with stage II–III and locally stage IV carbonate morphology. Most clasts are deeply weathered. Underlies gently sloping surfaces and consists of cut-and-fill terrace and pediment deposits about 55–75 m above modern floodplains. Contains beds and lenses of white, fine-to-medium sand, water-laid Lava Creek B tephra (about 640 ka; Lanphere and others, 2002). Tephra is locally present at base of older pediment deposits of unit Qv (Scott, 1963a), but is also present within or at top of older main-stream fluvial deposits of unit Qv (Hunt, 1954; Scott, 1972; Baker, 1973; Van Horn, 1976; Kirkham, 1977). Based on age and stratigraphic position of the Lava Creek B tephra, older deposits of unit Qv have been assigned an age of about 640 ka; however, younger deposits of Verdos Alluvium may be 410–475 ka (Kellogg and others, 2008, table 1). Thickness may be as much as 12 m underlying terrace treads; locally can be less than 1 m where deposits form a pavement of cobbles and boulders (Scott, 1963a)

Qao **Old alluvium (middle and early? Pleistocene)**—Poor to moderately sorted, sandy pebble- to boulder-sized gravel interbedded with red, yellow, and light-brown micaceous clay and sand. Unit is generally deposited on gently sloping aprons adjacent to questas, hogbacks, bedrock-cored upland surfaces, and modern drainage divides. Unit mantles pediment surfaces. Clasts are sub-angular and sub-rounded. Most are composed of Proterozoic igneous and metamorphic rocks and Tertiary volcanic rocks. Unit locally contains abundant chalcedony clasts, probably from the Maroon Formation (Kirkham and others, 2006). Locally gravel has an eolian-silt matrix (>20 percent). Many clasts exposed on surface show well-developed angular facets from eolian abrasion and are commonly deeply weathered. Most bedrock units beneath unit Qao are deeply weathered so that alluvium-bedrock contact is obscured. Soils formed in unit are similar to those formed in unit Qai, but the former have better developed carbonate morphology characterized by strong stage II to stage III Bk horizons, and locally K horizons with stage IV morphology. Unit underlies four sub-units of Como surface of Stark and others (1949). Deposit beneath youngest (lowest) surface has been correlated with Slocum Alluvium (Qs) in Colorado (Kratochvil, 1978). Unit Qao also includes unit Qa4 of Widmann and others (2005) and Kirkham and others (2006). Within Sulphur Mountain and Hartsel 7.5-minute quadrangles, it underlies two surfaces topographically higher than middle Pleistocene deposits, indicating initial degradation and planation of older pre-glacial Neogene geomorphic surfaces. Exposed thickness averages 4–6 m

QNr **Rocky Flats Alluvium (early Pleistocene and late Pliocene?)**—Massive to poorly stratified, reddish-brown, boulder-to-pebbly coarse sand, silty sand, and sandy clay. Unit is locally overlain by a thin mantle of silt and silty clay, possibly of eolian origin (Reheis, 1980; Shroba and Carrara, 1996). Near its type locality at Rocky Flats west of Denver, unit forms pediment veneer and paleovalley-fill deposits (Knepper, 2005). Many granitic clasts are deeply weathered. Soils commonly have an A/Bt/K profile with stage III to IV carbonate morphology overlying a soil with a Btk/K/Btk profile with stage I and stage III carbonate morphology. Dethier and others (2001) reported cosmogenic ages (10Be) for Rocky Flats Alluvium of about 1.5 Ma. Soil characteristics and paleomagnetic data indicate an age of 1.4–1.6 Ma (Birkeland and others, 1996). The presence of buried soils suggests that the lower part of unit could be much older, possibly 2 Ma (Birkeland and others, 2003). Based on cosmogenic dating (10Be and 26Al), Riihimaki and others (2006) concluded that incision and dissection of the Rocky Flats surface began between 1–2 Ma. Accordant beveled tops of Fountain Formation (PIPf) and Dakota Group (Kd) hogback are considered to be remnants of the Rocky Flats surface (Scott, 1963a). Rocky Flats surface generally is 120–125 m above modern streams and low floodplains. North of quadrangle and south of Roxborough Park, surface can be projected into the Front Range to an elevation of 6,850 feet (Scott, 1963a). Thickness can be as much as 12 m near mountain front and less than 3 m near eastern boundary of map area, due in part to erosion

Water-Laid and Lacustrine Deposits

Qbc **Bog clay and peat (Holocene and late Pleistocene)**—Mapped only in northeastern part of map in small depressions. Light-gray to dark-gray and dark-brown clay and silty clay with interbedded peat layers. Deposits are present in deflation basins along western margin of the Colorado Piedmont. Scott (1963a) noted two other possible origins for the deposits, being 1) mammalian-generated erosion by stamping and wallowing, and 2) damming of stream channels by younger loess deposits (unit Qlo). Estimated thickness 2–5 m

Qpl **Playa deposits (Holocene and late Pleistocene)**—Brown to light-brown and white, stratified, fine-grained silt, clay, and sand deposited in ephemeral lakes or ponds and shallow depressions produced by eolian deflation, mammalian-generated erosion (stamping and wallowing), and (or) probable collapse of subsurface evaporite deposits within South Park. Unit is locally overlain and interbedded with thin lenses and beds of pebble gravel and silty sand deposited sheetwash from adjacent ridges and stream alluvium. Estimated thickness 2–6 m, but may be much thicker in center of depressions

Alluvial and Mass-Movement Deposits

Qsw **Sheetwash deposits (Holocene and late Pleistocene)**—Poorly to moderately sorted, granule to boulder-gravel clasts in a silty sand to silty clay matrix. Unit is more commonly composed of pebble to cobble gravels in a silty sand matrix. Deposition due to downslope movement of soil and rock material by running water that is generally not confined to channels. Unit locally contains alluvium and colluvium undivided (Qac), debris flow deposits, and stream alluvium (Qa). Pedogenic surface soils commonly have A/Cu A/Cox, or A/Bw/Cox profiles, with weak and thin (<200 cm) argillic (Bt) horizons being more uncommon. Thickness 1–3 m

Qac **Alluvium and colluvium, undivided (Holocene and late Pleistocene)**—Unit typically consists of poorly to moderately sorted, sheetwash-alluvium deposits, perennial-stream deposits, and locally interfingered with fan deposits. Genesis of deposits is generally ambiguous and relative ages cannot be inferred. Alluvial component of unit locally consists of poorly to moderately sorted, pebble to cobble gravels with a silty clay to silty sand matrix in stream channels. Colluvial component of unit is commonly composed of an unsorted to poorly sorted, pebble gravel with angular to subangular clasts in a silty sand matrix. Unit locally contains material derived from debris flows, hyper-concentrated flows, sheetwash and rock fall. Thickness 2–5 m

Qf **Fan deposits (Holocene and late Pleistocene)**—Poorly to moderately sorted, weakly to moderately stratified, pebble and cobble gravel that contains thin beds and lenses of pebbly, silty sand. Deposits locally contain boulders. Deposited chiefly by sediment-charged avulsing streams, and locally by sheetwash and debris flows. Unit chiefly forms fan-shaped deposits at bases of steep slopes and gullies, where runoff is concentrated and channelized. Surface morphology of deposits is characterized by bar-and-swale micro-topography of less than 1 m in amplitude and minor stream dissection. Soils formed in deposits typically have A/Cox to A/Bw/Cox profiles. Deposit locally contains colluvium, sheetwash, and debris-flow deposits. Thickness 1–10 m

Mass-Movement and Glacial Deposits

Qc **Colluvium (Holocene to middle? Pleistocene)**—Unconsolidated deposits composed of clay, silt, sand, and angular to subrounded clasts ranging in size from granules to large boulders. Unit is generally composed of material eroded from local bedrock and (or) deposits beneath or upslope of colluvial deposit. Modes of transport and landforms associated with this unit indicate gravitationally driven, slow, downslope movement induced by frost creep, solifluction, and other periglacial processes, along with sheetwash, landslide, debris flow, hyperconcentrated flow, and rock fall. Estimated thickness 3–20 m

Qdf **Debris-flow deposits (Holocene to middle? Pleistocene)**—Lobate, hummocky, and fan-shaped deposits consisting of granules to boulders within a silty sand, clayey silt, and finer matrix. Deposits can be weakly stratified depending on existence of pore-water pressure and rate of deposition. Levees are common along margins of flows. Margins of flows tend to thin out to minimal thickness as flows spread across adjacent surfaces. Unit locally includes minor stream-flow and hyperconcentrated-flow deposits. Thickness 1–10 m

Qls **Landslide deposits (Holocene to late Pleistocene)**—Unsorted and unstratified to poorly stratified debris on slopes or at base of slopes. Generally consists of angular to subrounded, pebble- to boulder-sized clasts of various lithologies in a silty clay to silty sand matrix. Deposits generally have a lobate form. Micro-topography is hummocky with localized undrained depressions and has local relief of as much as 5 m. Landslides and landslide deposits are commonly translational processes sliding on a subsurface plane sub-parallel to parallel to land surface and forming on slopes that are underlain by shale, siltstone, and claystone overlying the Dakota Group along Front Range hogback belt or Dakota Sandstone in South Park (Kd). Unit locally includes deposits of rotational rock slides, rotational earth slides, and earth flows as defined by Varnes and Cruden (1996). Soils formed in deposits commonly have A/Cu, A/Cox, and A/Bw/Cox profiles. Landslide deposits are susceptible to reactivation due to natural processes (streams undercutting landslide toes or cuts excavated in toe of a landslide deposit) and human activities. Unit may locally contain thin sheetwash deposits. Estimated thickness 2–30 m

Qlso **Older landslide deposits (late and middle? Pleistocene)**—Generally characterized as unsorted to poorly sorted, unstratified to weakly stratified pebble- to boulder-sized clasts in a silty clay to silty sand matrix. Overall surficial expression and micro-topography of deposits is much more subdued than unit Qls. Soils formed in these deposits commonly have Bt horizons that are weakly to strongly developed blocky and prismatic structure. Thickness 3–30 m

Qt **Talus deposits (Holocene to middle? Pleistocene)**—Crudely sorted, angular rock fragments ranging from a few centimeters to several meters in diameter deposited along base of steep slopes and prominent cliffs as aprons, cones, fans, or pro-talus ramparts. Mechanisms of transport and deposition of unit includes rock fall, rock slide, and rock and snow avalanches. Locally contains debris-flow deposits where surface runoff has saturated and remobilized deposits. Tertiary intrusive rocks, Paleozoic sedimentary rocks, and Dakota Sandstone (Kd) are the main sources for talus deposits within region (Widmann and others, 2005), but in the Platte River, Kenosha, and Tarryall Mountains localized small deposits are composed of Proterozoic crystalline rocks. Thickness 2–10 m

Qrg **Rock-glacier deposits (Holocene and latest Pleistocene)**—Poorly sorted to unsorted, cobble- to boulder-sized, hummocky and lobate deposits along valley walls and on floors of alpine valleys. Unit consists of a veneer of matrix-free, angular cobbles and boulders that mantle a thicker mass of rock rubble containing a matrix of finer rock fragments. Lower part of unit locally contains interstitial ice, ice lenses, or an ice core. Valley walls commonly support lobate-shaped rock glaciers, whereas valley floors commonly contain tongue-shaped rock glaciers (Widmann and others, 2005). Rock fragments on and within rock-glacier deposits are primarily derived from steep slopes and upslope cliffs chiefly by rockfall and locally by rock slide and avalanche. Orientations of curvilinear ridges and gullies on rock-glacier deposits indicate downslope motion. Most of the rock-glacier deposits in Colorado are of latest Pleistocene or early Holocene age (Meierding and Birkeland, 1980), but mantle relict ice bodies formed during former glacial episodes. Active rock glaciers in Front Range, north of Bailey quadrangle, have estimated rates of movement of 1–10 cm/yr (White, 1971, 1976). Thickness 20–50 m

Glacial Deposits

[Glacial deposits primarily consist of non-sorted and non-stratified till deposited by ice, as well as deposits of stratified sand and pebble gravel (stratified drift) deposited by meltwater streams and mass-movement deposits]

Qtp **Till of Pinedale age (late Pleistocene)**—Nonsorted and nonstratified, subangular to rounded boulders to granules in a silty sand matrix. Unit locally contains beds and lenses of stratified silty sand and pebble gravel. Surface morphology of deposit is characterized by partially buried large boulders surrounding depressions filled with beds and lenses of silt, sand, and clayey silt; fully exposed sub-angular to rounded cobbles are abundant on surface. Sharp crests of lateral moraines show little modification by erosion. Undrained depressions are common and locally are closely enough spaced to produce knob-and-kettle topography. Surface soils have A/Cox, A/Bw/Cox, and A/Bt/Cox profiles on moraine crests. Cambic (Bw) and weak argillic (Bt) horizons probably contain about 1–5 percent more clay than underlying till (<2 mm-size fraction). Most of biotite-rich granite and gneiss clasts within soil are unweathered, and disintegrated clasts are rare. Unit locally may include till of Bull Lake and pre-Bull Lake age. Previous studies have found radiocarbon (14C) and cosmogenic-exposure ages of 12–30 ka for till of unit Qtp (Nelson and others, 1979; Madole, 1986; Schildgen and Dethier, 2000; Benson and others, 2004, 2005). Estimated thickness 2–40 m

Qtb **Till of Bull Lake age (late middle Pleistocene)**—Nonsorted and nonstratified, subangular to rounded boulders to granules in a silty sand matrix. Landforms underlain by unit Qtb are commonly rounded and more subdued than those formed by unit Qtp and are generally present further downvalley than unit Qtp (for example, Jefferson Creek in South Park). Surface morphology is characterized by very few exposed boulders, subdued, hummocky topography with gentle slopes, and generally no undrained depressions. Bull Lake age till is generally overlain by a thin loess mantle (<1 m) and generally supports more vegetation than Pinedale age till. Clasts in Bull Lake age till are more deeply weathered than those in till of Pinedale age, so that biotite-rich crystalline rocks can be easily disaggregated with a hammer or shovel. Pedogenic soils on surface of unit Qtb have A/Bt/Cox profiles and are thicker and more oxidized. Argillic (Bt) horizons have strong blocky, prismatic structure and probably contain at least 5 percent more clay than underlying till (<2 mm size fraction). North of map area near Nederland, cosmogenic 10Be and 26Al dating yields minimum ages for surface boulders on till of Bull Lake age of 101 ± 21 and 122 ± 26 ka (Schildgen and others, 2002). Uranium-trend age estimates for Bull Lake age till near Allenspark, of 130 ± 40 ka, support these data (Shroba and others, 1983). K-Ar and 230Th/U analyses from Wind River Range and West Yellowstone, respectively, suggest that the onset of Bull Lake glaciation was before 167 ± 6.4 ka (possibly 190 ka) and culminated at about 122 ± 10 ka (Sharp and others, 2003; Pierce, 2004). Estimated thickness 20–30 m

Qti **Till of Pinedale, Bull Lake, and pre-Bull Lake age, undivided (late and middle Pleistocene)**—Nonsorted and nonstratified, subangular to rounded boulders to granules in a silty sand matrix. Unit is mapped in areas where deposits of units Qtp and Qtb are indistinguishable or where Qtp overlies considerable deposits of Qtb and may locally include till of pre-Bull Lake age. Glacial deposits of pre-Bull Lake age have been identified along Tarryall Creek in the northwest part of Bailey quadrangle by Widmann and others (2005). Thickness 3–30 m

Eolian Deposits

Qlo **Loess (late and middle? Pleistocene)**—Nonstratified, well-sorted, wind-deposited sandy silt and locally sandy, clayey silt derived by wind erosion from flood plains and possibly Cretaceous bedrock sources by westerly or northwesterly paleowinds. Soils formed in upper part of unit have A/Bt/Btk/Bk profiles with stage I–II carbonate morphology (Kellogg and others, 2008). Loess overlies deposits as young as Louviers Alluvium (mapped to north on Denver West quadrangle), but locally overlies Broadway Alluvium (Qb) along South Platte River about 70 km northeast of map area (Lindvall, 1980). Thin (≤50 cm) layers of pebbly, clayey, sandy silt that locally mantle Slocum Alluvium (Qs) and older alluviums (Qao) in the Colorado Piedmont may consist in part of loess that contains clasts from underlying gravelly alluvium. Deposits of sheetwash locally eroded from unit Qlo contain a minor amount of coarse sand and granules and a few pebbles.

Loess in northeastern Colorado records two episodes of deposition at about 10–13 ka and 14–20 ka (Muhs and others, 1999). Holocene loess is locally extensive in eastern part of Colorado (Madole, 1995), but none has been recognized within or near map area. Some loess near Littleton, Colo., near northeast corner of map area (older loess of Scott, 1962, 1963a), may be as old as 120–170 ka and may be correlative with eolian silt and sand about 90 km northeast of map area that yielded thermoluminescence age estimates of about 150 ka (Forman and others, 1995). Pre-Bull Lake till near Allenspark, about 25 km north of Nederland, is locally mantled by about 15 cm of loess (Madole and Shroba, 1979). Some of the closed depressions on till of Pinedale age (Qtp, Qti) may contain thin (≤50 cm) deposits of loess or silty sheetwash deposits derived chiefly from loess. Dust deflated from flood plains in the Colorado Piedmont has influenced properties of soils downwind of flood plains (Reheis, 1980). Alpine soils in and near cirques on east side of the Continental Divide, north of map area, contain eolian dust (Birkeland and others, 1987, 2003; Muhs and Benedict, 2006). Thickness about 1.5–3 m

Tertiary Sedimentary Rocks of the Front Range

Tg **Gravel deposits (Pliocene? and Miocene?)**—Boulder gravel deposits mantling ridges along major drainages on Elkhorn surface southwest of Kenosha Pass. Deposits are composed of subrounded to well-rounded boulder gravel with a coarse sand matrix. Some of the coarse sand in matrix may be due to in situ deep weathering and dissaggregation of granitic boulders to grus. Some boulders exceed 2 m in diameter. Deposits within the Pine Junction-Pine region contain clasts of the Mount Evans batholith. Deposit preserved along Michigan Hill, near Jefferson, Colo., could possibly be correlative to Wagontongue Formation (unit Tw, Miocene) mapped within Antero Reservoir region. Estimated thickness 20–120 m

Tdg **Gravel at Divide (Miocene)**—Cobble to boulder gravel interbedded with weakly stratified sand, silt, and clay. Unit contains large clasts of hornblende andesite, described by Wobus and Scott (1977) to be derived from Thirtynine Mile volcanic field, intermixed with smaller pebbles and cobbles from Pikes Peak batholith and Proterozoic metamorphic and igneous rocks. However, Temple and others (2007) noted that volcanic clasts could also have been derived from Signal Butte, about

18 km to the west. Exposure within quadrangle is in extreme southeast corner. Thickness <50 m

Tertiary Sedimentary and Volcanic Rocks of South Park

Tw **Wagontongue Formation (Miocene)**—Interbedded pebble-cobble gravel, sandstone, and siltstone. Clasts are subrounded to well rounded and consist of Proterozoic, Paleozoic, and Tertiary lithologies. Age determined from a jawbone from an upper Miocene equid (Stark and others, 1949). Deposit is preserved in a syncline northeast of Antero Reservoir filling a paleovalley cut into Wall Mountain Tuff (Twm) and Antero Formation (Ta). Approximate thickness 150 m

Ts **Sedimentary rocks of Fairplay paleovalley (Oligocene)**—Interbedded mudstone, pebble conglomerate, sandstone, pebbly sandstone, and thin (1–3 cm) beds of tuff. Mudstones are reddish brown with bed thickness commonly less than 1–5 m. Pebble conglomerates form as lenses filling alluvial channels within mudstone. Kirkham and others (2006) reported that these sedimentary rocks, which crop out approximately 6 km south of Fairplay, filled a paleovalley called the Fairplay paleovalley. This unit consists of upper and lower parts. The principal difference between lower and upper parts of unit is that pebble conglomerate in lower part consists of clasts derived from upper Paleozoic units and has bimodal rounded and angular clasts, while conglomerate in upper part has a higher percentage of subrounded clasts of Tertiary intrusive rocks and Proterozoic metamorphic and intrusive rocks (Kirkham and others, 2006). Based on fossil correlations and stratigraphic position, Brown (1940) correlated these rocks to upper member of Oligocene Antero Formation (Ta). Estimated thickness 250–300 m

Tt **Tuff (Oligocene)**—Mapped approximately 6 km south of Fairplay. Light-gray to gray, crystal-lithic tuff with a fine-grained matrix consisting of glass shards and few small biotite and feldspar crystals. Tuff is comprised of 10–20 percent pumice clasts and locally as much as 40 percent (Kirkham and others, 2006). Contains sparse angular to subangular rock fragments composed of sandstone, mudstone, and igneous rocks. Kirkham and others (2006) reported a $^{40}Ar/^{39}Ar$ age of 33.47 ± 0.15 Ma from a pumice clast within tuff. Unit has been correlated to Antero Formation (Brown, 1940; De Voto, 1964; Bryant and others, 1981b). However, this unit may be correlative with Badger Creek Tuff or Grizzly Peak Tuff (Shannon, 1988; Fridrich and others, 1991; McIntosh and Chapin, 2004). Kirkham and others (2006) noted that size (1–10 mm) of pumice clasts indicates that this unit is proximal to its source. Maximum thickness is approximately 100–110 m (Kirkham and others, 2006)

Ta **Antero Formation (Oligocene)**—The Antero Formation was formed as fossiliferous, freshwater lacustrine and low-energy fluvial deposits within a inter-montane basin formed to west and north of volcanic breccia complex of Thirtynine Mile Andesite (35–36.5 Ma) (McIntosh and Chapin, 2004). Based on tuffaceous sediments, tuff beds, and ignimbrites, McIntosh and Chapin (2004) determined a $^{40}Ar/^{39}Ar$ age of 34.3–33.4 Ma for the Antero Formation. Formation intertongues with Badger Creek Tuff and contains volcanic rocks associated with Mount Aetna cauldron. Formation consists of three informal members. Upper member is composed of interbedded, pebble-cobble conglomerate and lenticular sandstone beds. Middle member consists of a basal fine-grained tuff overlain by interbedded, thin, discontinuous, lenticular beds of shale and tuff, with rare discontinuous layers of limestone. Stark and others (1949) noted that a limestone bed approximately 6-m thick is within the middle member and extends almost entirely around the ancient-lake basin. Lowest member consists of discontinuous and lenticular beds of tuff, sandstone, lacustrine limestone, pebble conglomerate, and thin beds of fissile shale. Limestone, which makes up lowest part of section, forms a more continuous deposit of algal beds and mounds along edge of Lake Antero (Stark and others, 1949). Exposures within quadrangle are limited and generally less than 5 m thick. Stark and others (1949) measured a maximum thickness of approximately 610 m south of quadrangle

Ttc **Tallahassee Creek Conglomerate (Oligocene)**—Polylithic, boulder-cobble conglomerate containing Proterozoic, Paleozoic, and Mesozoic clasts. Contains beds of tuff along Tarryall Creek. Maximum thickness about 10 m

Twm **Wall Mountain Tuff (Eocene)**—Gray, purplish-gray, dark-pink, and grayish-purple rhyolite ash-flow tuffs. Unit is locally vitric. Contains phenocrysts (<1 cm in length) of plagioclase, biotite, and sanidine. McIntosh and Chapin (2004) dated Wall Mountain Tuff at 36.69 ± 0.09 Ma by $^{40}Ar/^{39}Ar$. Weathers reddish brown to yellowish buff; resistant and well exposed in most places forming cliffs and ledges. Moderately to densely welded with black vitrophyre common. Mapped along crest of strike ridges northeast of Hartsel and within south-central South Park. Flow layering is common, but very irregular in orientation and not parallel or only sub-parallel to base of unit, suggesting post-depositional flowage. Thickness about 30 m

Tan **Andesitic flow breccia, ash-flow tuff, and related intrusive rocks (Eocene)**—Quartz-bearing, hornblende-biotite and biotite andesite flow breccia and ash-flow tuff mapped by Bryant and others (1981a), who after chemical analyses called it a rhyodacite (Bryant and others, 1981b). These rocks are exposed within a paleovalley approximately 2 km southeast of Kenosha Pass, beneath Wall Mountain Tuff (Twm) just northwest of Hartsel, and associated with a volcanic neck at Signal Butte in southeast part of quadrangle (Goss, 1985). Bryant and others (1981b) obtained a K-Ar age of 37.8 ± 0.9 Ma from biotite from flow beneath Wall Mountain Tuff and a zircon fission-track age of 36.4 ± 1.9 Ma for flow southeast of Kenosha Pass. They correlated the flow preserved in paleovalley with rocks of similar age derived from Montezuma stock or other nearby intrusive bodies. Signal Butte is a porphyritic hornblende andesite, emplaced as a series of four hypabyssal plugs (Goss, 1985) and has a sphene fission-track age of 43.3 ± 3.9 Ma (Marvin and others, 1974) and a zircon fission-track age of 42.2 ± 2.1 Ma (Naeser, unpub, data). Thickness of paleovalley flow is approximately 100 m

Tpb **Biotite quartz latite porphyry (Eocene)**—Gray to light yellowish-gray latite porphyry of Baker Lake and Jefferson Hill. Unit consists of equant, euhedral phenocrysts of sanidine, andesine, and biotite in an aphanitic felsic matrix. Bryant and others (1981b) report a zircon fission-track age of 37.6 ± 1.5 Ma, showing time of cooling and crystallization. Unit is resistant, forming spheroidal outcrops and tors

Tqp **Monzogranite of Boreas Mountain, Mount Guyot, and Bald Mountain (Eocene)**—Gray to light yellow-brown porphyritic monzogranite of Bald Mountain, Montgomery Gulch, and Mount Guyot stocks, located in northwest part of quadrangle. Composition locally grades from granodiorite to monzogranite (Bryant and others, 1981b). K-Ar ages of biotite from Mount Guyot plug are 44.0 ± 1.5 Ma (Bryant and others, 1981b). Fission-track ages of zircon, sphene, and apatite range from 35.5 ± 1.4 Ma to 42.7 ± 8.2 Ma for rocks of this unit (Bryant and others, 1981b). Widman and others (2005) reported that cross-cutting relationships indicate that unit Tqp is younger than sills of unit Tmp

Tmp **Monzogranite porphyry (Eocene)**—Pale-green to light yellowish-brown porphyritic monzogranite with chloritized fracture surfaces. Unit composes sills and stocks within Montgomery Gulch-Mount Silverheels area. Sills appear to be contemporaneous to or younger than Montgomery stock in northwest part of quadrangle (Widmann and others, 2005). Rock consists of plagioclase, hornblende, and biotite phenocrysts in a light-gray to gray, aphanitic groundmass composed of plagioclase, quartz, biotite, augite, hypersthene, hornblende, magnetite, apatite, allanite, and zircon (Widman and others, 2005)

Laramide and Post-Laramide Sedimentary and Volcanic Rocks of South Park and the Front Range

Txc **Syntectonic conglomeratic unit (Paleocene)**—Poorly sorted, subangular to subrounded, boulder- to cobble-sized conglomerate with interbedded coarse-grained sandy lenses ranging from 0.5–2.0 m in thickness. Most igneous clasts in unit are weathered. Clasts predominantly derived from unit Yg. Interpreted as a syntectonic conglomerate deposited coeval with displacement along the Elkhorn fault (Ruleman and Bohannon, 2008). Unit thickness variable, but generally less than 100 m

South Park Formation (Paleocene and Upper Cretaceous)

Tsf **Fine-grained arkosic member (Paleocene)**—Interbedded and lenticular, pale pinkish-brown, greenish-gray, and gray, calcareous, mudstone, siltstone, silty sandstone, and conglomerate. Unit is highly friable, easily eroded and generally forms swales within South Park. Clasts primarily consist of Proterozoic igneous and metamorphic lithologies (Sawatzky, 1967). At northern extent of exposure, the unit is in fault contact with Proterozoic rocks along Elkhorn fault. To the south, unit pinches out to where it unconformably overlies coarse, conglomerate member (unit Tsc) (Wyant and Barker, 1976). Bryant and others (1981b) report a biotite K-Ar age of 56.3 ± 1.3 Ma from a tuff bed in this unit. Thickness ranges from approximately 100 to 1,000 m (Barker and Wyant, 1976; Wyant and Barker, 1976; Kirkham and others, 2006)

Tsl **Link Spring Tuff Member (Paleocene)**—Light yellowish-brown, light-gray to gray, laminated to thinly bedded tuff. Unit contains a few beds of brown and brownish-green volcaniclastic breccia and andesitic flows. Unit contains sparse leaf impressions (Wyant and Barker, 1976). Bryant and others (1981b) obtained a K-Ar age of 59.7 ± 2.0 Ma for Link Springs Tuff Member. Maximum thickness is approximately 200 m

Tsc **Conglomerate member (Paleocene)**—Light yellowish-brown, brown, greenish-brown, and greenish-gray, conglomerate, silty sandstone, and mudstone. Bedding ranges from massive to thick (>1 m) lenticular beds. Weakly to moderately lithified and forms prominent strike ridges throughout South Park (Ruleman and Bohannon, 2008). Locally contains abundant silicified wood fragments and debris, which become less abundant to the west. Kirkham and others (2006) report that unit coarsens and thickens to west. Johnson (1935) noted that crossbeds within unit dip to the east indicating a source area to the west. Clasts consist of Paleozoic gray quartzite, chert-pebble conglomerate, red silty sandstone, and Cretaceous and Paleocene hypabyssal igneous rocks. Clast lithologies and ages indicate a west-northwest source area from the Mosquito Range as uplift and erosion occurred on the Sawatch anticlinorium (Wyant and Barker, 1976; De Voto, 1988; Kirkham and others, 2006). There is a distinct basal cobble conglomerate bed composed of quartzite and porphyritic igneous clasts. Bryant and others (1981b) obtained a K-Ar age of 65.5 ± 1.6 Ma on biotite from a tuff bed in unit Tsc. Kirkham and others (2006) obtained ^{40}Ar/^{39}Ar ages of 66.6 ± 0.5 Ma and 66.4 ± 0.4 Ma on biotite from an intermediate to mafic volcanic clast and monzogranite clast, respectively. Kirkham and others (2006) noted that the lithology of a fine-grained igneous rock from Buckskin Gulch in the Mosquito Range having biotite with a K-Ar age of 63.6 ± 2.3 Ma (Bookstrom and others, 1987) was similar in composition to an igneous clast collected by Widmann and others (2005) from unit Tsc, having biotite dated by ^{40}Ar/^{39}Ar at 64.08 ± 0.11 Ma. This suggests that at least part of unit Tsc is younger than 64 Ma (Kirkham and others, 2006). Thickness ranges from approximately 440 to 1,700 m

TKsr **Reinecker Ridge Volcanic Member (Paleocene and Upper Cretaceous)**—Consists of three parts. Upper and middle units are comprised of interstratified conglomerate and thin beds of light-gray to light yellowish-brown, crossbedded tuffaceous sandstone. Conglomerate is well cemented with iron oxide and consists of well-rounded cobbles in a tuffaceous sandy silt matrix. Clasts are comprised of various lithologies of extrusive, porphyritic rocks derived from flows of lower member. Lower part consists of dark-brown, dark-gray, greenish-gray, grayish-green, and purple porphyritic hornblende andesite flows and breccias. Widmann and others (2005) classified volcanic rocks as trachyandesite, andesite, and dacite. Flow breccias contain clasts of same composition as matrix (Kirkham and others, 2006). Sawatzky (1967) originally obtained a K-Ar age of 56 ± 2.6 Ma from a basal flow. However, Bryant and others (1981b) determined that sampled rocks were altered and yielded an erroneous young age. An ^{40}Ar/^{39}Ar age of 66.94 ± 0.25 Ma on hornblende from lowest exposed flow in Como 7.5-minute quadrangle considered to be minimum age of these flows (Widmann and others, 2005). Kirkham and others (2006) obtained an ^{40}Ar/^{39}Ar age of 68.8 ± 0.8 Ma from flows exposed within Fairplay East 7.5-minute quadrangle. Unit thickness is approximately 100 to 300 m

Ksvs **Lower volcaniclastic member (Upper Cretaceous)**—Exposed in a small area on western slopes of Reineker Ridge, approximately 9 km southeast of Fairplay. It is composed of two lenses of volcaniclastic rocks (Kirkham and others, 2006). Unit consists of well-bedded, poorly sorted, medium- to coarse-grained, argillaceous, lithic sandstone ranging from reddish brown to greenish brown depending on the oxidation state of iron. Unconformable on Pierre Shale (Kp) (Kirkham and others, 2006). Thickness is approximately 140 m

TKda **Dawson Arkose (Paleocene and Upper Cretaceous)**—Gray, white, light yellowish-gray, reddish-brown, and light-brown, lenticular and crossbedded, conglomerate, sandstone, siltstone, and shale, grading from a basal conglomerate to an upper shale. Most clasts and grains are well rounded, loosely cemented, and have abundant pore space (Scott, 1963b). Leaf impressions are abundant within sandstone layers. Average thickness is approximately 450 m

Ka **Thin Cretaceous Andesite Dikes (Upper Cretaceous?)**—Thin, lens- to tabular-shaped bodies of grayish-brown, greenish-gray, to black andesite present in northeast part of quadrangle along South Platte River area. Generally weathers to brownish gray. Thickness ranges between <3 cm to 3 m. Scott (1963b) notes that dikes intruding northwest-trending faults are sub-vertical and dikes intruding northeast-trending faults are sub-horizontal. He also notes that the andesite within the northwest-trending faults is intruded into fault gouge and brecciated by later faulting. These dikes may be associated with rocks eroded and deposited in Dawson Arkose (TKda) of the Denver Formation (Lovering, 1935)

Pre-Laramide Sedimentary Rocks of the Denver Basin and South Park

Kl **Laramie Formation (Upper Cretaceous)**—Olive-gray to yellowish-brown shale; gray, medium-grained, sub-angular to sub-rounded, well-graded and well-sorted sandstone; reddish-brown chert-rich conglomerate; and lignitic coal beds. Sandstone is loosely cemented by both calcium carbonate and silica, and friable. Conglomerate is harder and more resistant. Yellow limonitic staining is common throughout formation and concentric iron concretions are common within sandstone layers. Lignitic coal beds range from 0.1–2 m in thickness. Formation contains abundant leaf impressions and wood fragments. Formation consists of fine-grained deposits of marine and fluvial origin apparently deposited within an estuarine environment. Thickness within Kassler 7.5-minute quadrangle approximately 200 m (Scott, 1963b)

Kf **Fox Hills Sandstone (Upper Cretaceous)**—Subdivided into an upper 45–47 m section consisting of olive-brown to light-gray friable sandstone, a middle, more resistant 8-m section of olive-gray to yellowish-gray, massive sandstone, and a lower section of soft, olive-brown sandy shale. Unit represents a sequence of nearshore trangressive and regressive phases between underlying, marine Pierre Shale (Kp) and overlying estuarine Laramie Formation (Kl). Locally, pelecypods are found within more resistant, middle sandstone. Thickness within Kassler 7.5-minute quadrangle is estimated to be 56–60 m (Scott, 1963b)

Kp **Pierre Shale (Upper Cretaceous)**—Consists of olive-gray and medium- to dark-gray, calcareous shale interbedded with few thin beds of fine-grained, brownish-gray sandstone. Locally contains ironstone and limestone concretions. Prominent sandstone members are Hygiene Sandstone and Apache Creek Sandstone Members, which are possibly exposed along east side of upper Trout Creek (Kirkham and others, 2006). Thin, bentonitic layers are common. Shale and bentonite beds are susceptible to swelling. Pierre Shale lies conformably above Niobrara Formation (Kn). In the Denver Basin, Scott (1963b) gave a total thickness of approximately 1,580 m. In South Park, estimated thicknesses range from about 820 m (Stark and others, 1949) to approximately 1,800 m (Barker and Wyant, 1976; Wyant and Barker, 1976)

Kn **Niobrara Formation (Upper Cretaceous)**—Consists of Smoky Hill Shale Member (younger) and Fort Hays Limestone Member, which are not mapped separately. Smoky Hill Shale Member consists of pale to yellowish-brown, soft, thin-bedded, platy calcareous shale and interbedded thin limestone layers. Total thickness of 125 m and mapped together, herein. Weathers pale gray to white and contains many bentonite beds, forming a distinctive yellow soil (Widmann and others, 2005). Fort Hays Limestone Member is a gray, dense, micritic limestone with individual beds as thick as 2 m. Contains abundant large inoceramid bivalve (oyster) fossils in Denver Basin. Thickness of Fort Hays Limestone Member is about 105 m in South Park (Widmann and others, 2005)

Kb **Benton Group (Upper Cretaceous)**—In Denver Basin, consists of three formations in descending order: Carlile Shale, Greenhorn Limestone, and Graneros. These formations are not mapped separately. Carlile Shale consists of three members in descending order: grayish-brown, hard calcarenite containing abundant shell fragments (Juana Lopez Member); gray silty sandstone (Blue Hill Member); and yellowish-gray, soft calcareous shale (Fairport Member). The Carlile conformably overlies the Greenhorn Limestone, which in upper part consists of a gray, dense limestone and hard calcareous shale (Bridge Creek Member); middle part of gray, shaly calcareous sandstone (Hartland Shale Member); and lower part of grayish-brown, thin beds of hard calcareous sandstone and shale with a marker bentonite bed at base (Lincoln Member). Graneros Shale consists of dark-gray, hard, clayey shale and siltstone.

In South Park, exposure of Benton Group is limited. It generally forms topographic swales and hummocky, slumped surfaces. Stark and others (1949) reported thick bentonite beds (0.5 m thick) within South Park region proximal to Reinecker Ridge. Widmann and others (2005) noted that shale is typically much darker colored than overlying Pierre Shale (Kp). In Kassler 7.5-minute quadrangle, Benton Group is approximately 182 m thick (Scott, 1963b), and in South Park thickness is approximately 75 m (Widmann and others, 2005)

Knb **Niobrara Formation and Benton Group, undivided (Upper Cretaceous)**—Mapped together in Sulphur Mountain vicinity due to limited and poor exposure. Mapping primarily in float and a few exposures in road cuts. Generally mantled by a thin veneer of surficial deposits too thin to map. Total thickness approximately 180 m

Ku **Pierre Shale, Niobrara Formation, and Benton Group, undivided (Upper Cretaceous)**—Mapped together in South Park where exposure is poor or limited and contacts cannot be identified. Kirkham and others (2006) noted that areas where unit Ku is mapped are more likely underlain by more erosion-resistant Niobrara Formation (Kn). Total thickness approximately 2,030 m

Kd **Dakota Group or Dakota Sandstone (Lower Cretaceous)**—In Kassler area, this group consists of South Platte Formation and underlying Lytle Formation. South Platte Formation consists of five distinct units as described by Scott (1963b). From top to bottom they are 1) approximately 26 m of light-gray to medium-gray, tabular to massive, fine- to medium-grained, crossbedded sandstone; 2) a shale interval 6 m thick with interbeds of gray to dark-gray and yellowish-gray, fine-grained sandstones; 3) Kassler Sandstone Member (Scott, 1963b) which consists of a basal chert and quartzite pebble conglomerate with overlying yellowish-gray to light yellowish-brown, fine- to coarse-grained, cross-laminated sandstones with an approximate thickness of 22 m; 4) an interval of gray to brown siltstone approximately 20 m thick with localized lenses of fine-grained sandstone; and 5) light-gray to yellowish-gray, fine-grained, crossbedded sandstone approximately 17 m thick. Lytle Formation is comprised of yellowish-gray to light yellowish-brown, medium- to fine-grained sandstone and pebble conglomerate. Pebbles within conglomerate are well-rounded and composed of quartz, quartzite, chert, and petrified wood; conglomerate generally near base of unit. Lytle Formation is approximately 12 m thick (Scott, 1963b). Overall thickness of Dakota Group near Kassler is approximately 95–100 m.

In South Park, Dakota Group consists only of Dakota Sandstone. It is a light-brown to light-gray, fine- to coarse-grained, crossbedded, well-sorted sandstone and moderately well-sorted pebble conglomerate (Kirkham and others, 2006). Weathers brown to reddish brown. Kirkham and others (2006) estimated a maximum thickness of 76 m

Jm **Morrison Formation (Upper Jurassic)**—Mapped only in South Park, this unit grades from interbedded shale and fine- to medium-grained sandstone to interbedded green, red, and gray claystone to basal micritic limestones (Widmann and others, 2005). Claystones are generally bentonitic and deeply weathered. Formation thickness ranges from approximately 60–106 m (Stark and others, 1949; Barker and Wyant, 1976; Widmann and others 2005, 2006)

Jmr **Morrison Formation and Ralston Creek Formation, undivided (Upper Jurassic)**—Mapped only within Kassler area following Scott (1963b). Unit consists of Morrison Formation in upper part and Ralston Creek Formation in lower part. Upper approximately 18 m of Morrison Formation consists of red to reddish-brown, variegated silty claystone with localized interbeds of limonitic, gray, medium-grained sandstone. The underlying 50 m is comprised of light-gray, locally limonitic siltstone and claystone. This section has interbedded, resistant, light-gray to gray limestone with fossilized algal mats and freshwater mollusks. Basal part of unit is comprised of a lower yellowish-gray to medium-gray, massive to thick-bedded, crossbedded, fine- to medium-grained, calcareous sandstone that is approximately 13 m thick. This basal sandstone is overlain by approximately 13 m of interbedded medium-gray to reddish-brown siltstone; thin, discontinuous, sparitic limestone beds; and limonitic sandstone beds. Ralston Creek Formation consists of interbedded yellowish-gray, fossiliferous limestone, gypsum beds, silty calcareous shale, and fine-grained sandstone. Limestone beds contain freshwater gastropods (Scott, 1963b). Freshwater gastropods, together with gypsum beds, indicate a coastal lagoonal depositional setting for the formation. Maximum thickness is less than 13 m (Scott, 1963b). Total thickness of combined Morrison and Ralston Creek Formations is approximately 55–60 m

KJdm **Dakota Group (Lower Cretaceous) and Morrison Formation (Upper Jurassic), undivided**—Unit mapped where limited exposure conceals precise location of contact between the two formations

ȾPl **Lykins Formation (Triassic? and Permian)**—Mapped only within Denver Basin. Formation consists of five members deposited in a marine transgressive sequence (Scott, 1963b). Members are not mapped separately. Upper member, Strain Shale, consists of 90 m of reddish-brown, well-stratified, micaceous, fine-grained, silty sandstone and siltstone with some green siltstone layers. Middle member, Forelle Limestone, consists of 5 m of pink, wavy-laminated, sandy, marine, algal limestone. Lower member is about 40 m thick and includes undivided Bergen and underlying Harriman Shale, which consist of interbedded, reddish-brown and green siltstone, with a thin (<1 m), laminated, red-weathering, gray and yellow crystalline limestone (Falcon Limestone Member) between them

Pl **Lyons Sandstone (Cisuralian)**—Mapped only in Denver Basin. Consists of yellowish-gray, white, reddish-brown to light-red, and pink, crossbedded, fine to medium-grained eolian sandstone (Scott, 1963b). Upper part of unit is coarse-grained sandstone and conglomerate containing large muscovite flakes (>0.5 cm) and lenticular beds of conglomerate at base (Scott, 1963b). Thickness is approximately 70 m

Pg **Garo Formation (Permian)**—Mapped only in South Park. Red to pink, and locally light-gray, medium- to well-sorted, fine- to medium-grained sandstone and conglomerate; calcareous; crossbeds as thick as 2 m are prominent; and ripple marks are locally preserved (Widmann and others, 2005; Kirkham and others, 2006). Previously mapped as conformably overlying and interbedded with Maroon Formation (PIPm) (DeVoto, 1965a; 1965b), indicating coeval deposition. However, other workers have recognized probable unconformities both above and below formation (Singewald, 1942; Stark and others, 1949). Widmann and others (2005) and Kirkham and others (2006) assigned a Permian age based on Devoto’s work and additional supporting work by Lozano (1965). We have followed this age designation. Thickness of formation varies from approximately 20 to 70 m

PIPf **Fountain Formation (Cisuralian and Pennsylvanian)**—Mapped only in Denver Basin (Scott, 1963b). Red to reddish-brown, arkosic, thin- to thick-bedded, coarse-grained sandstone and crossbedded fluvial conglomeratic sandstone with thin layers of dark reddish-brown, siltstone and shale. Coarse-grained, conglomeratic beds and lenses commonly fill shallow channels cut into surrounding sandstone. Sandstone locally bleached light tan to white. Formation contains thin, discontinuous, green siltstone and shale layers. Clasts in conglomerate consist of only Proterozoic crystalline rocks and are well rounded to subrounded. Scott (1963b) reported thicknesses ranging from 350 to 685 m, with thickness being thickest in Colorado Springs area and decreasing to south along eastern margin of Front Range

PIPm **Maroon Formation (Cisuralian to Middle Pennsylvanian)**—Mapped only in South Park. Light-yellow to orangish-red, medium- to fine-grained, interbedded sandstone and thinly laminated siltstone and shale. Beds are tabular, trough cross-stratified, and finely laminated. Formation locally contains lenses of pebble- to cobble-conglomerate. Widmann and others (2005) mapped thin, discontinuous layers of dark-gray to reddish-gray, micritic limestone and limey siltstone. Conglomeratic facies are more prominent in north and fine-grained sandstone facies are more widespread to south (Widmann and others, 2005). Formation thickness is approximately 1,000 m

IPm **Minturn Formation (Middle Pennsylvanian)**—Mapped only in South Park. Light yellowish-brown to reddish-gray, interbedded pebble- to cobble-conglomerate, reddish-brown siltstone, fine- to coarse-grained sandstone, and dark-gray, micritic limestone. Widmann and others (2005) noted that finer grained sandstone layers are planar, and trough cross-stratified beds are coarser. In addition, they noted that conglomeratic facies on southeast flank of Mount Silverheels, near margin of quadrangle approximately 9 km north of Fairplay, Colo., possibly represents a basin margin or paleovalley. Fossil fragments, or fossil hash, are preserved within some of the limestone beds. Kirkham and others (2006) mapped uppermost limestone, Jacque Mountain Limestone Member, within Fairplay East 7.5-minute quadrangle, being top of Minturn Formation. Thickness as much as 1,800 m

PIPmm **Maroon and Minturn Formations, undivided (Cisuralian to Middle Pennsylvanian)**—Unit mapped where exposures of contact between the two formations is limited

Mlw **Leadville Limestone and Williams Canyon Formation, undivided (Mississippian)**—Exposed only within Manitou Park in the southeastern corner of quadrangle. Upper Leadville Limestone is chiefly composed of gray to light-brown, micritic limestone containing brachiopods, bryozoans, ostracodes, and conodonts (Hill, 1983). Mississippian age and classification of Leadville Limestone and Williams Canyon Formation follows that of Temple and others (2007). Leadville Limestone has a thickness of approximately 15 m. Basal Williams Canyon Member is chiefly composed of massive- to medium-bedded, calcitic sandstone, lime mudstone, dolomitic mudstone, and thin-bedded, lensoidal sandstone with a distinct basal medium- to coarse-grained, well-rounded quartzite bed (<30 cm in thickness) unconformably overlying Manitou Formation (Temple and others, 2007). Lenses of sandstone have sub-rounded to well-rounded, frosted quartz grains. The total maximum thickness of the undivided unit is approximately 40–45 m

Om **Manitou Formation (Lower Ordovician)**—Mapped only in Manitou Park area within southeast corner of quadrangle. Fine-grained, pink to light-gray, micritic limestone and dolomite. Temple and others (2007) described two members of formation. Upper member consists of light-pink to pinkish-gray, medium-grained, sparitic limestone and dolomitic limestone, locally containing thin chert layers, with a thickness of approximately 20 m. Limestone is locally bioturbated and fossiliferous, containing assemblages of trilobites, conodonts, and gastropods. Lower member is about 15 m thick and is composed of pink to light grayish-red, fine-grained, micritic limestone and dolomitic limestone. Total thickness of formation is approximately 35–40 m

Ꞓs **Sawatch Formation (Upper Cambrian)**—Purplish-pink, red to light-brown, and white, medium- to coarse-grained, crossbedded quartzite. Bedding thickness averages about 1 m. Unit generally fines upward with basal beds being coarse grained with lenses of quartz pebble conglomerate in a medium-grained quartzite matrix. Grains are well sorted and rounded to well rounded with frosted surfaces. Quartzite is locally glauconitic. Forms sandstone dikes along South Platte River corridor near Bailey, Colo. Weathers to a mottled light-brown color. Temple and others (2007) defined four informal members of formation: a red to maroon, porous, less-resistant sandstone; grading into two gray to light-brown quartzite members; and a basal conglomerate. Estimated thickness is 15–20 m

MꞒ **Leadville Limestone and Williams Canyon Formation (Mississippian), Manitou Formation (Lower Ordovician), and Sawatch Formation (Upper Cambrian), undivided**—Mapped where limited exposure prevents precise location of contacts between formations or where sub-horizontal bedding makes outcrop widths too narrow to depict at map scale (Temple and others, 2007)

Ordovician(?), Cambrian(?), or Neoproterozoic(?) Intrusive Rocks

OZd **Diabase**—Black to reddish-brown, deeply weathered potassic feldspar-bearing augite diabase forming dikes between South Park and Tarryall Creek drainage

Proterozoic Intrusive Rocks

Radiometric-age determinations by several methods show that Proterozoic intrusive rocks in Bailey quadrangle were emplaced during three principal time intervals. These major intrusive episodes were recognized and formalized by Tweto (1987) as rocks of 1,074–1,092 Ma (Unruh and others, 1995) Pikes Peak batholith and associated intrusive bodies, including Redskin stock, Mesoproterozoic Berthoud Plutonic Suite (roughly 1,400 ± 25 Ma), and Paleoproterozoic Routt Plutonic Suite (roughly 1,700 ± 25 Ma). In order to more clearly represent age and composition and plutonic suite, the following map unit label scheme was created following that of Kellogg and others (2008):

Age: X=Paleoproterozoic (2,500–1,600 Ma), Y=Mesoproterozoic (1,600–900 Ma)

Composition: g=granite, gd=granodiorite, qd=quartz diorite, and gm=gabbro and monzogranite; in addition, where appropriate, textural and (or) mineralogic variants that are mapped separately within an intrusive complex are symbolized with an additional lower-case letter (for example, p=porphyritic, f=fine-grained, fp=fine-grained porphyritic).

Pluton: P=Pikes Peak batholith and R=Redskin stock.

Thus, the symbol for the coarse-grained porphyritic phase of the Pikes Peak batholith is YgPcp; the symbol for the gabbro and monzonite associated with the Redskin stock is YgRm.

Classification of intrusive rocks follows that of Streckeisen (1976), in which “granite” includes syenogranite and monzogranite.

Rocks of the Pikes Peak Batholith and Related Rocks of the Redskin Stock (Mesoproterozoic)

YgRf **Redskin granite fine-grained facies**—White to pink, massive, fine-grained granite forms core of stock and Boomer and China Wall cupolas. This facies is associated beryllium-bearing greisen deposits (Hawley and others, 1966). Rock is a two-mica granite containing quartz, microcline, and albite in approximately equal proportions. Boomer cupola is formed by a fine-grained aplitic, quartzose muscovitic two-alkali-feldspar granite (Hawley and others, 1966)

YgRp **Redskin porphyritic granite facies**—White, orangish-pink, and pink, massive, medium-grained seriate porphyritic granite forming a zone surrounding core of main Redskin stock. Porphyritic facies is a two-mica granite with quartz, microcline, and albite in equal proportions (Hawley and others, 1966). Hydrothermal alteration has created beryllium-bearing greisen deposits (Hutchinson, 1964; Hawley and others, 1966)

YgRg **Redskin equigranular granite facies—**White to pink, medium-grained, equigranular granite composed of biotite, quartz, albite, and perthitic microcline. Quartz, microcline perthite, and albite are in proportions of 33:43:24 (Hawley and others, 1966). Granular facies forms outer zone facies of Redskin stock

YgRm **Gabbro and monzogranite associated with Redskin stock and Pikes Peak batholith**—Black to green, coarse-grained labradorite-olivine-hypersthene-ilmenite gabbro forms outer ring of a small pluton at southern margin of Redskin stock. Core of this body is composed of a light-pink to brownish-white monzogranite ranging in texture and composition from a coarse-grained hornblende-biotite monzogranite to a aphanitic-porphyritic biotite monzogranite (Hawley and others, 1966). Hawley and others (1966) noted that discordant contacts and funnel-shape of intrusive body indicates that it is a hypabyssal intrusion younger than unit Yg, and older than Redskin stock

Rocks of the Pikes Peak Batholith (Mesoproterozoic)

YgP **Pikes Peak Granite**—Pinkish-orange to light-gray, medium- to coarse-grained, subequigranular biotite- and biotite-hornblende granite with feldspar crystals as long as 2.5 cm. Forms large, slabby or rounded outcrops and weathers to orange-brown grus that contains abundant feldspar and mica fragments. U-Pb zircon ages range from 1,074 ± 3 to 1,092 ± 2 Ma, with late stage, hypabyssal pegmatites in west and south ranging from 1,059 ± 2 to 1,062 ± 2 Ma (Unruh and others, 1995). A more recent age for eastern side of batholith has a U-Pb zircon age of 1,085.6 ± 2.5 Ma (Smith and others, 1999). Unit surrounds coarse-grained porphyritic facies (unit YgPcp) within batholith (Hawley and Wobus, 1977)

YgPcp **Pikes Peak coarse-grained porphyritic phase—**Light-pink to pink, seriate porphyritic biotite granite with tabular microcline phenocrysts as long as 5 cm. Intruded by fine-grained, porphyritic granite and has diffuse, gradational boundaries with coarse-grained unit YgP (Wobus and Scott, 1977)

YgPf **Pikes Peak fine-grained granite**—Pink, fine-grained equigranular biotite granite. Locally grades into fine-grained, porphyritic granite (YgPfp)

YgPfp **Pikes Peak fine-grained porphyritic granite**—Pink to brownish-red, holocrystalline, fine- to medium-grained porphyritic biotite granite with phenocrysts of spherical gray quartz, and subhedral microcline and oligoclase are abundant. Fluorite is a common accessory mineral. Resembles Windy Point Granite of Pikes Peak batholith mapped south of quadrangle, and represents late phase, rapidly cooling intrusive bodies within batholith. U-Pb zircon ages range from 1,074–1,092 Ma (Unruh and others, 1995). Appears to have intruded Pikes Peak Granite (unit YgP) (Wobus, 1976b), but age difference is too small to be detected by U-Pb zircon age determinations (Unruh and others, 1995). Unit is dominantly deeply weathered. Breaks into angular masses and platy pieces

YgPqg **Pikes Peaks monzogranite to granodiorite**—Medium- to coarse-grained porphyritic hornblende-biotite monzogranite to granodiorite. Locally contains xenocrysts of sodic labradorite with albite rims

YgPs **Syenite and fayalite granite of Pikes Peak batholith**—Fine- to coarse-grained pegmatitic syenite and fayalite granite comprising younger-phase intrusive centers within Pikes Peak batholith. Fayalite granite is primarily composed of a medium-grained granite with minor amounts of fayalite. Dominant minerals are pink, perthitic feldspar and ferrorichterite amphibole (Beane and Wobus, 1999). Accessory minerals include fluorite, zircon, and chevkinite. Wobus (1976b) stated that interlocking tabular fabric in fayalite granites makes the rock very resistant to weathering and erosion. Syenite granite tends to be coarser-grained than fayalite granite and contains green albite-oligoclase feldspars and dominant mafic mineral is ferrohastingsite (Wobus, 1976b). Syenite body near Lake George contains large, elongate inclusions of alkali gabbro as much as 0.5 m long. Ring dikes surrounding Lake George pluton are composed of quartz syenite and fayalite granite. An $^{40}Ar/^{39}Ar$ age of 1,074 ± 1 Ma has been determined by Unruh and Premo (unpub. data, 2008)

Intrusive Rocks of the Berthoud Plutonic Suite (Mesoproterozoic)

Yg **Monzogranite and granite**—Yellow-orange, light-pink, and pink-brown, biotite-muscovite monzogranite, biotite monzogranite, and leucogranite. Unit contains aplite and pegmatite. Locally foliated. Garnet and sphene are accessory minerals. SHRIMP U-Pb zircon ages taken from samples collected at Elkhorn Ranch (UTM NAD 27: E0431568, N4337945) and Kenosha Pass (UTM NAD 27: E0435390, N4365565) yielded ages of 1,391 ± 27 Ma and 1,429 ± 15 Ma, respectively (reference needed). Rocks mapped in this unit are very similar to those mapped as Silver Plume Granite in Denver West quadrangle (unit YgSP of Kellogg and others, 2008). In some previous work all such rocks were called Silver Plume Granite. Because of uncertainty whether they formed from the same magma or intrusive episode, the term Silver Plume is not applied to these rocks in accordance with the recommendation of Tweto (1987)

Intrusive Rocks of Uncertain Age (Mesoproterozoic or Paleoproterozoic)

YXp **Pegmatite and aplite**—Coarse-grained to very coarse grained, white to light-pink, inequigranular plagioclase-microcline (or perthite)-quartz-mica rock that forms irregular-shaped pods, commonly zoned dikes, and intrusive bodies cutting monzogranite and granite (Yg) and all older rocks; relatively few pegmatites cut Pikes Peak Granite (YgP). Some pegmatites contain microcline crystals more than 1.0 m long. Mica is mostly biotite, but locally includes or is entirely muscovite. Accessory minerals include tourmaline, beryl, garnet, and magnetite. Unit consists predominantly of pegmatite, which commonly grades into and is intimately mixed with aplite, which also forms separate dikes and bodies. Aplite is similar in composition to pegmatite but is a pinkish-light brown, fine- to medium-grained, leucocratic, equigranular rock

YXmr **Mixed metamorphic and igneous rocks**—Unit consists of at least two of the following units in equal percentages: monzogranite (Yg), biotite gneiss and schist (Xb), and felsic gneiss (Xf). Xenoliths of units Xb and Xf within unit Yg show diffuse boundaries and represent intense and profuse intrusion, and initial assimilation of the metamorphic rock into monzogranite (Yg)

YXqgm **Mixed metamorphic and igneous rocks**—Unit consists of estimated equal proportions of unit Xqg intruded into country rock consisting of biotite gneiss and schist (unit Xb) and hornblende gneiss (unit Xh) with diffuse bodies of unit Yg and YXp. Contacts between igneous component and metamorphic rocks are diffuse and indicate profuse intrusion and assimilation of metamorphic rocks into igneous bodies. Samples from Observatory Rock 7.5-minute quadrangle yielded SHRIMP U-Pb zircon ages ranging from 1,430 ± 15 Ma to 1,437 ± 6 Ma and probably reflect metamorphism related to intrusion of unit Yg (W.R. Premo, unpub. data, 2008)

YXgd **Granodiorite and monzogranite of unknown age**—Gray, medium- to coarse-grained, equigranular to porphyritic, massive to weakly foliated quartz-plagioclase-microcline-biotite-hornblende tonalite, granodiorite, and monzogranite. May include a younger, medium-grained monzogranite phase and an older, medium- to coarse-grained granodiorite phase

Intrusive Rocks of the Routt Plutonic Suite (Paleoproterozoic)

Xqg **Monzogranite and granodiorite**—Light-pink to gray, fine- to coarse-grained, massive to strongly foliated monzogranite and granodiorite. Unit is locally intruded by monzogranite of unit Yg. Plutonic body of this suite mapped south of Hartsel, yielded a SHRIMP U-Pb zircon age of 1,705 ± 7 Ma (W.R. Premo, unpub. data, 2008). A correlative plutonic body mapped south of Singleton, along North Fork of South Platte River yielded SHRIMP U-Pb zircon ages cores with inherited cores ranging from ≈1,650 to 1,750 Ma and an imprecise age on high-U magmatic rims at 1,461 ± 33 Ma (W.R. Premo, unpub. data, 2008). Younger age is most likely related to 1,425– to 1,445–Ma plutonic event within Front Range. One possible interpretation is that age of this plutonic body is ≈1,665 Ma and that it was metamorphosed at ≈1,445 Ma (W.R. Premo, written comm., 2008)

Xbm **Mixed metamorphic and igneous rocks**—Mapped southwest of Pine Junction, unit consists of unit Xb (described below) as well as abundant light-gray to white leucosomes, commonly ranging from 0.1 to 10 cm in thickness, but locally exceeding 1 m in thickness. It is uncertain whether formation of leucosomes was from in situ partial melting, or from profuse injection of granitic bodies. Two U-Pb zircon dates from melt phase in similar migmatitic gneiss from Clear Creek, approximately 30 km north of the quadrangle boundary, are 1,693 ± 35 Ma and 1,698 ± 3 Ma (Kellogg and others, 2008); one date from a leucosome in migmatite sampled along Elk Creek in the Pine, Colo. 7.5-minute quadrangle is 1,692 ± 6 Ma and 1,780 ± 9 Ma sampled from a melanosome (W.R. Premo, unpub. data, 2005). These data suggest peak metamorphism and partial melting in region at ≈1,695 Ma

Xqd **Quartz diorite**—Mapped in Badger Mountain-Puma Hills region. Gray to dark-gray, fine- to medium-grained, massive to strongly foliated, locally porphyritic, biotite and biotite-hornblende quartz diorite. Contains abundant locally derived xenoliths of country rock, mainly biotite gneiss and schist (Xb). Primarily forms border phase around larger granodiorite plutons and is intruded by granodiorite (Wobus, 1976b). Locally forms small stocks and intrusive bodies

Xgg **Granitic gneiss**—Light- to medium-gray and pinkish-gray, fine- to medium-grained, weakly to strongly foliated monzogranite, granodiorite, and trondhjemite, with lesser amounts of biotite, hornblende, and muscovite. Within Mount Logan region (north of Singleton), unit locally contains abundant xenoliths of biotite gneiss (Xb). Age has been inferred by Sheridan and others (1972) to be same as that of Boulder Creek Granodiorite mapped to north in Denver West quadrangle (Kellogg and others, 2008). North of map area, a preliminary U-Pb zircon age from a foliated granodiorite on Mount Morrison in Morrison 7.5-minute quadrangle is 1,771 ± 11 Ma, and a foliated monzogranite from near Deer Creek in southern Harris Park 7.5-minute quadrangle is 1,776 ± 10 Ma (W.R. Premo, unpub. data, 2005)

Xpgd **Porphyritic biotite granodiorite gneiss**—Biotite granodiorite gneiss containing potassic feldspar grains as much as 2 cm in length. Commonly strongly foliated. Forms an irregular plutonic body and concordant stocks near Pine Gulch (south of Pine Junction). Contacts with biotite gneiss (Xb) and mixed metamorphic rocks (Xbm) are diffuse. Rb-Sr age determination on similar foliated plutonic rocks in Front Range indicate an age of 1,710 Ma (Hedge, 1969); however, this age could either be whole-rock or mineral isochron ages due to possible metamorphic resetting

Metasedimentary and Metaigneous Rocks (Paleoproterozoic)

Xb **Biotite gneiss**—Gray to black, fine- to medium-grained, equigranular, well-foliated, biotite-quartz-plagioclase gneiss and schist. Locally contains abundant sillimanite (<30 percent). Locally garnetiferous with average size of crystals <0.5 cm. Unit includes a few lenses of hornblende gneiss (Xh) and calc-silicate rock. Near younger intrusive bodies (Yg and YgP), unit contains abundant lenses, pods, sills, and dikes of pegmatite (YXp) and rocks similar in composition to Yg and YgP. Near Pine, a melanosome of biotite gneiss in migmatite yielded a U-Pb zircon age of 1,780 ± 9 Ma (W.R. Premo, unpub. data, 2005). In northwestern parts of Tarryall Mountains, unit contains sillimanite-cordierite-quartz gneiss and sillimanitic biotite-muscovite gneiss

Xbh **Interlayered biotite gneiss and schist, hornblende-plagioclase gneiss, and amphibolite**—Mapped south of Shaffers Crossing and Pine Junction. Gray to black, fine- to medium-grained, biotite-plagioclase gneiss and schist, amphibolite, hornblendite, and hornblende gneiss. Unit contains minor amounts of calc-silicate rock. Commonly contains abundant dikes, sills, and pods of units YgP and Yg. Biotite-plagioclase gneiss and amphibolite make up 10 to 20 percent of unit

Xbs **Biotite-sillimanite gneiss and schist**—Mapped in Farnum Peak region, Kenosha Mountains, and north-northwest of Pine Nook in northeast part of quadrangle. Light-gray to black, fine- to coarse-grained, well-foliated, biotite-quartz-plagioclase-sillimanite gneiss. Commonly contains muscovite as a secondary mineral. Unit is locally interlayered with biotite gneiss (Xb) and hornblende gneiss (Xh). Locally contains garnets >1 cm in diameter

Xca **Calc-silicate gneiss, marble, and amphibolite**—Mapped north-northeast of Jefferson Lake. Fine- to medium-grained, interlayered dark-green calc-silicate gneiss, white and opaque marble, and black amphibolite. Calc-silicate dominantly consists of clinopyroxene, hornblende, calcite, epidote, scapolite, and sphene. Marble contains clinopyroxene, hornblende, and other silicates (Barker and Wyant, 1976). Unit contains a few lenses of medium- to coarse-grained quartzite

Xf **Quartz-feldspar gneiss**—Mapped in northeast and northwest corners of quadrangle, in Elkhorn region, and along Tarryall Creek. Gray, dark-gray, white, pinkish-gray, and tan moderately foliated to well-foliated, layered quartz-plagioclase-microcline-biotite gneiss. Ranges from fine to coarse grained, but is chiefly medium grained. Proportion of minerals ranges widely. Layers typically 10 cm to several tens of meters thick and commonly are wavy. Locally contains layers of foliated monzogranite and granodiorite. Contains minor thin layers of hornblende gneiss and amphibolite. U-Pb date on weakly foliated rock of monzogranitic composition in northwestern part of Indian Hills 7.5-minute quadrangle is 1,776 ± 4 Ma (Kellogg and others, 2008). Weathers light-yellow-brown to pink-yellow-brown in rounded, spheroidal outcrops

Xfh **Quartz-feldspar gneiss and hornblende gneiss**—Mapped in Georgia Pass region. Interlayered dark-gray and light-gray, well-foliated quartz-feldspar gneiss (Xf) and hornblende-plagioclase gneiss and amphibolite (Xh) in approximately equal proportions. Unit locally contains very few layers and lenses of calc-silicate rock

Xh **Hornblende-plagioclase gneiss and amphibolite**—Mapped in Georgia Pass region, proximal to Webber Park along Tarryall Creek, and near Pine Notch in northeast corner of quadrangle. Dark-gray to black, greenish-black, and white, weakly to strongly foliated, layered, fine- to coarse-grained, hornblende-plagioclase gneiss and black to greenish-black amphibolite containing variable amounts of biotite, quartz, and augite. Layering ranges from less than 1 cm to greater than 1 m. Commonly has black-and-white mottled texture due to weathered plagioclase (white) and hornblende (black). Amphibolite contains >50 percent amphibole

Xhc **Hornblende gneiss and calc-silicate gneiss**—Black to dark-gray, greenish-black, greenish-white, and greenish-gray, interlayered hornblende-plagioclase gneiss and amphibolite (Xh), with lesser amounts of interlayered calc-silicate gneiss (<20 percent). Unit locally contains layers of white to light-gray marble of thickness less than 1 m. Mapped primarily in Webster-Kenosha Pass region in northwest part of quadrangle and southeast of Farnum Peak in south-central part of map, near bodies of Paleoproterozoic rocks of igneous origin (Xgg, Xqd, and Xqg)

Xhq **Amphibolite, marble, and quartzite**—Interlayered amphibolite. Quartzite, coarse-grained, locally siliceous, white to light-gray marble, quartz-rich calc-silicate gneiss and schist, and quartz-sillimanite-muscovite-biotite gneiss and schist. Marble and quartzite layers locally as thick as 10 m

Geologic History of the Bailey Quadrangle

The Bailey, Colo. 1:100,000-scale quadrangle lies within two physiographic and geologic provinces in central Colorado: 1) the Front Range and 2) South Park. Most of the Front Range is composed of Proterozoic rocks ranging in age from 1,790 Ma to 1,074 Ma. Along the eastern flanks and within the Denver Basin, sedimentary rocks ranging from Pennsylvanian to Cretaceous are deformed and steeply tilted to the east. Upper Cretaceous through Paleocene rocks were deposited in the foreland (that is, the Front Range eastern flank) and hinterland (that is, South Park) of this thrust and reverse fault system developed during the Late Cretaceous to Paleocene Laramide orogeny. Within South Park, rocks range in age from Pennsylvanian to Miocene with Quaternary deposits indicating tectonic subsidence of the basin. These rocks record five major geologic episodes: 1) the Paleozoic Anasazi uplift that formed the Ancestral Rockies, 2) the Late Cretaceous to Paleocene Laramide orogeny, 3) widespread Eocene to Oligocene volcanism, 4) Oligocene–Quaternary tectonics, and 5) Quaternary glacial episodes.

Proterozoic History

The Proterozoic history recorded in the Front Range begins with a sequence of gneiss and schists dating back to approximately 1,790 Ma. These metasedimentary and metaigneous rocks consist of biotite gneiss and schist (Xb), calc-silicate (Xca), amphibolite (Xh), and felsic gneiss (Xf). These rocks may represent a package of interlayered pelitic, clastic, and volcanic rocks deposited within back-arc basins and along the southwestern margin of the Archean North American craton. The margin of the Archean craton was just north of the southern Wyoming stateline. Syntectonic deformation of these deposits occurred as accretion of successive island arc complexes and associated rocks developed along the continental margin (Reed and others, 1987).

Coeval to back-arc deposition and accretion of the island arcs, widespread igneous activity took place from approximately 1,776 ± 10 Ma to 1,646 ± 13 Ma (W.M. Premo, unpub. data, 2006) (Xqg and Xgg). Composition of these plutonic bodies is chiefly granodiorite and monzogranite. Profuse intrusion of plutonic rocks into the surrounding country rocks induced a migmatization event and created mixed rocks mapped as migmatite (units Xbm and Xqgm). North of the quadrangle, this migmatization event has been dated at 1,750 Ma to 1,697 Ma (Reed and others, 1993; W.M. Premo, unpub. data, 2005; Kellogg and others, 2008).

During the Mesoproterozoic, plutonic bodies of predominantly monzogranite composition (Yg) were emplaced and locally bodies of mixed rock (that is, migmatite) (YXmr) were formed in the adjacent country rock. These Mesoproterozoic monzogranites have been dated at 1,429 ± 15 Ma to 1,391 ± 27 Ma, contemporaneously with the Silver Plume Granite of the central and northern Front Range dated at 1,424 ± 6 Ma (W.M. Premo, unpub. data, 2006). One of the Mesoproterozoic plutons was derived from partial melting of the lower crust and emplaced at depths of 8 to 9 km (Anderson and Thomas, 1985), and perhaps that model is applicable to the others. Regionally, the country rock was hotter than 300º C and locally hotter than 550º C as indicated by $^{40}Ar/^{39}Ar$ studies (Shaw and others, 1999).

The final event of the Proterozoic occurred with the intrusion of the Neoproterozoic Pikes Peak batholith between 1,092–1,074 Ma (Unruh and others, 1995). Two pulses of igneous activity forming the Pikes Peak batholith occurred at ≈1,090–1,080 Ma and ≈1,075–1,070 Ma. Individual plutonic bodies and intrusive centers, such as that at Lake George, were generated from alkali basaltic magma derived from the mantle (Wobus and Anderson, 1978). Beane and Wobus (1999) suggested that the parallel alignment of Neoproterozoic faults and linear, plutonic bodies indicated that the Pikes Peak batholith was emplaced within an extensional tectonic regime, possibly being rift-related. Together, these suggest a tectonic setting involving post-orogenic, extensional collapse. However, constraints on this tectono-magmatic model are limited and the tectonic setting of the Neoproterozoic is uncertain.

In additon to Proterozoic faulting, linear sandstone and quartzite dikes cut Proterozoic rock throughout the quadrangle. These dikes are chiefly composed of well-sorted fine-grained sand, varying from brown to red in color and locally spotted white (Vitanage, 1954; Scott, 1963b; Peterson, 1964). In the southeastern corner of the quadrangle within Manitou Park, these dikes contain brecciated sandstone indicating a polyphase deformational cycle (Temple and others, 2007). Peterson (1964) notes within the South Platte 7.5-minute quadrangle, the dikes are encased in brecciated Proterozoic country rock indicating faulting of the country rock, healing of the fault, reopening of the same fault, and finally, filling of the fissure with sand. Vitanage (1954) suggested the source of the sand was the Sawatch Quartzite before lithification occurred, but this is still highly debatable.

Paleozoic and Pre-Laramide Mesozoic History

From Cambrian through Mississippian times, quartz-rich sand, shale, and carbonate deposits accumulated regionally in fluvial plains and shallow seas, forming a thin continental platform section that extended across much of the Southern Rocky Mountains, including all of South Park and the Front Range. Remnants of the platform section are preserved in a broad open syncline in the southeast corner of the quadrangle near Mount Deception (Temple and others, 2007), as well as the Colorado Springs area. The same section is preserved in its entirety throughout the Mosquito Range, which borders South Park west of the Bailey quadrangle (Tweto, 1974; Widmann and others, 2004; 2005), but it is absent everywhere northeast of South Park in a belt that extends into western Nebraska (Rocky Mountain Association of Geologists, 1972).

The missing section is the result of widespread Late Mississippian to Early Pennsylvanian erosion or non-deposition in an uplifted area that is typically referred to as part of the Ancestral Rocky Mountains. Its northeast orientation, which crosses the present-day Front Range, shows that it had little in common with the present Rocky Mountain geography, a fact that is commonly observed in other uplifts of that age (Kluth, 2007; Nesse, 2007). Nesse (2007) proposed the term Anasazi uplifts for these uplifts of Mississippian to Pennsylvanian age to avoid the misconception of coincidence with later uplifts and we adopt that term herein. The relative roles of denudation versus non-deposition are poorly understood beneath the Denver Basin, but denudation is the most represented geomorphic process within the Bailey quadrangle where similar sections of Upper Paleozoic rocks are preserved on either side of the eroded zone.

Anasazi-uplift geography changed in the Pennsylvanian and Permian with the deposition of the Pennsylvanian Minturn (IPm), Pennsylvanian and Permian Belden (not within map area), Fountain (PIPf), and Maroon (PIPm) Formations, and the Permian Garo (Pg) Formation, which were derived from western parts of the earlier uplift and covered eastern parts of it. About 500 m of mostly fluvial red and pink, arkosic sandstone and conglomerate of the Fountain Formation (PIPf) were shed eastward from the present-day Front Range to cover the northeastern extent of the earlier area (the part now buried beneath the Denver Basin). Similar fluvial deposits of the Belden, Minturn, Maroon, and Garo Formations in western South Park and the adjacent Mosquito Range (Kluth, 2004) were shed west off the narrowed erosional area. The fluvial deposits are para-conformable on Mississippian limestone where the Leadville Limestone and older units have not been eroded, otherwise they rest directly on Proterozoic rocks. That fact and the preponderance of sandstone over coarser grained sedimentary rocks suggest that relief and depth of denudation were only modest at best. The presence of marine limestone horizons interbedded with the Pennsylvanian clastic rocks on the west side of the uplift (Widmann and others, 2004; 2005) indicates that the uplift might not have progressed far above sea level at any time. Thus, the Anasazi uplifts within this region are actually more related to differential subsidence than anything else. Nonetheless, the large volume of the redbeds suggests considerable erosion over a wide area.

Permian eolian deposits of the Lyons Sandstone (Pl) and Permian and Triassic fluvial and near-shore deposits of the Lykins Formation (TRPl) overlie the thick clastic sequences of the Fountain Formation along the east side of the Front Range. By the Late Jurassic, the present Front Range area was mostly covered by fluvial and lacustrine deposits of the Morrison Formation (Jm) and the Ralston Creek Formation in the Bailey area. Near the end of the Early Cretaceous, major subsidence coeval with a rise in sea level caused transgression of the Western Interior seaway over the entire area of the present Front Range. Deposition commenced as shoreline deposits of the Dakota Group (or Sandstone) (Kd), were followed by more than 2 km of marine shale and minor amounts of sandstone and limestone (Benton Group [Kb], Niobrara Formation [Kn], and Pierre Shale [Kp]).

The Western Interior seaway began to withdraw from the quadrangle area after 69 Ma, the age of the youngest ammonite zone in the Pierre Shale (Scott and Cobban, 1965; Cobban, 1993). This age is based on $^{40}Ar/^{39}Ar$ dating of tuffs outside the quadrangle but in the same ammonite zone (Obradovich, 1993). The Upper Cretaceous-lower Tertiary rocks overlying the Pierre Shale record the uplift history, starting with the regressive shoreline deposits of the Fox Hills Sandstone, followed by coastal-plain deposits that formed the sandstones and coal beds of the Laramie Formation (from which the Laramide orogeny is named). The Laramie Formation is in turn overlain by the fluvial conglomerates, sandstones, and claystones of the Arapahoe and Denver Formations (not within map area) (Raynolds, 1997, 2002). Uplift in this area was geologically rapid; only a few million years (≈5 m.y.) separate the ages of the uppermost marine deposits of the Pierre Shale and the earliest conglomerates of the terrestrial Arapahoe Formation, which contains clasts derived from Proterozoic basement rocks. During this short period, the newly formed Rocky Mountains rose from the sea, and more than 2 km of upper Paleozoic and Mesozoic sedimentary rocks were eroded from the core of the Front Range. Peterson (1964) mapped mafic dikes of probable Cretaceous or early Tertiary age. These dikes are fine-grained, dark gray to greenish black and are composed chiefly of plagioclase, pyroxene, and magnetite with a diabasic texture. Dikes are generally 2–3 meters in width and have sharp contacts with the country rock. The age of these dikes is still debatable, but could be related to Laramide deformation.

The Laramide Orogeny

The Laramide orogeny was a widespread period of lithospheric buckling, in the form of arches and uplifts, that lasted approximately 25 m.y. during the Late Cretaceous and Paleogene (75–50 Ma) (Tikoff and Maxon, 2001). The deformation affected most of the eastern Rocky Mountains and large parts of the adjacent mid-continent region where later burial has obscured the ancient uplifts (Tikoff and Maxon, 2001).

This time period (20 (25?) m.y.) coincided with widespread volcanism in Colorado. Most of the igneous activity occurred northwest, south, or southwest of the Bailey quadrangle, but some volcanism spatially overlaps parts of the buckled and uplifted regions within the quadrangle. Several thin, discontinuous volcanic flows, lahars, and tuffs of Laramide age are present in the South Park region, which make up the two formal members of the South Park Formation (Tsl and TKsr). The igneous activity is commonly included as part of the Laramide orogeny, but there is no reason to assume it had anything to do with the mechanical arching or uplifts. Rather, it is more logically a product of subduction-related melting that would have occurred even in the complete absence of the structural deformation that can be more strictly defined as being Laramide.

Laramide uplift is evident throughout the Bailey quadrangle between South Park and the eastern range front near Kassler in the northeast corner of Bailey quadrangle, and Manitou Park in the southeast corner of Bailey quadrangle. These areas contain early Tertiary age and older sedimentary rocks that exhibit steep dips related to folding associated with Laramide basement uplifts. Proterozoic rocks are exposed everywhere in this area except where Paleozoic strata are preserved in a faulted syncline in the Mount Deception and Dakan Mountain 7.5-minute quadrangles. A sedimentary apron, now largely eroded, lapped onto the flanks of the uplift by the end of the Eocene. Conglomerate and arkose deposits are still preserved east of the present range front at the latitude of the Bailey quadrangle (Dawson Arkose, unit TKda) and are commonly cited as evidence for Front Range uplift and erosion during the latest Cretaceous through early Eocene. Since the structural dip of the Dawson is less than that in older units along the range front, a large amount of structural relief is assumed to have formed just prior to and during its deposition. Conglomerate of similar age occurs in South Park on the west side of the uplift (South Park Formation). Within South Park, however, the older units in the South Park Formation coarsen and thicken to the west (Kirkham and others, 2006), away from the uplift, and crossbeds are consistent with easterly transport away from a western source (Johnson, 1935). Clasts of Paleozoic sedimentary and Cretaceous and Paleocene intrusive rock types further suggest a source in the Mosquito Range or beyond (Wyant and Barker, 1976; De Voto, 1988; Widman and others, 2005). Coarse-grained and immature sand components of the South Park Formation probably had a source in a nearby terrain of granitic rock. Basement rocks in the Mosquito Range were covered by a thick section of Phanerozoic sedimentary rocks in the Paleocene, leaving the Laramide uplift to the east as the only nearby source of exposed granitic rock. Thus, there was probably mixing of east- and west-draining river systems that transported clastic material into the South Park Basin.

The eastern edge of the Laramide uplift corresponds to the present-day range front near Kassler. It is primarily a zone of moderate-to-steeply east-dipping strata that forms a large east-facing monocline. Typical cross sections drawn across the uplifted margin, for example those of Nesse (2007), depict as much as 4 km of structural relief. The relief is largely due to folding, but partly to overthrusting on faults that are now buried. Along the eastern flank of the Front Range in the Kassler 7.5-minute quadrangle, the Rampart Range fault cuts out the Paleozoic and Mesozoic sections.

The western structural edge of the Laramide uplift in South Park is delineated by the Elkhorn fault (fig. 1). The Elkhorn fault is a high-angle thrust or reverse fault with a north-northwest orientations and it is well exposed in two areas. In the northwest corner of Bailey quadrangle at Georgia Pass, a steep-to-moderate, east-dipping fault contact between mixed Proterozoic crystalline rocks (east side) and a 44-Ma monzogranite stock that intrudes Cretaceous marine strata (west side) is interpreted to be the southern branch of the Williams Range thrust fault (fig. 1). North of the Bailey quadrangle this branch is quasi-continuous with the Williams Fork thrust fault (Kellogg and others, 2008). A southern branch is partially exposed between Elkhorn Ranch and Muley Gulch in the east-central part of South Park where it dips

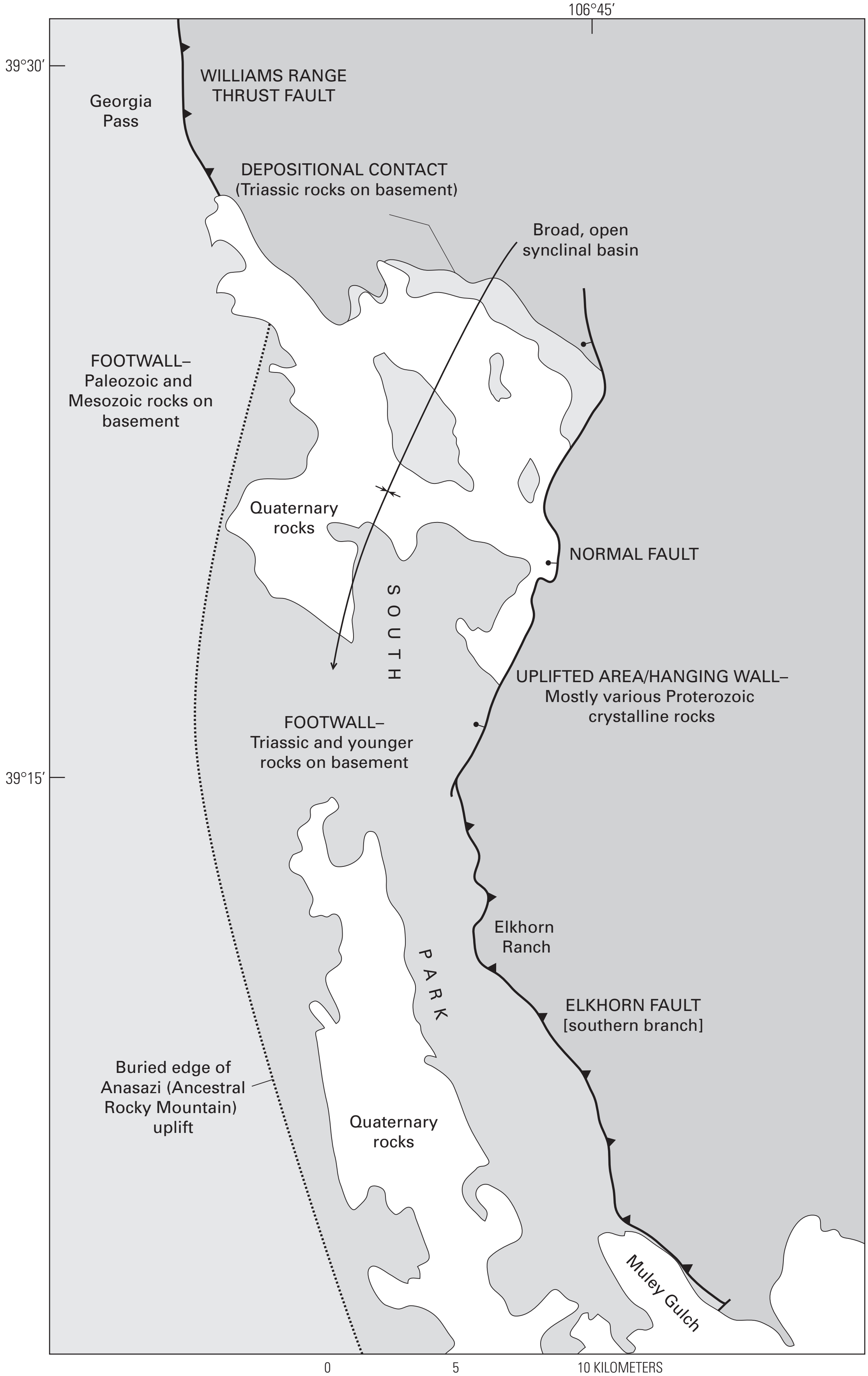
106°45′
39°30′
WILLIAMS RANGE THRUST FAULT
Georgia Pass
DEPOSITIONAL CONTACT (Triassic rocks on basement)
Broad, open synclinal basin
FOOTWALL– Paleozoic and Mesozoic rocks on basement
Quaternary rocks
NORMAL FAULT
SOUTH
UPLIFTED AREA/HANGING WALL– Mostly various Proterozoic crystalline rocks
FOOTWALL– Triassic and younger rocks on basement
39°15′
Elkhorn Ranch
PARK
ELKHORN FAULT [southern branch]
Buried edge of Anasazi (Ancestral Rocky Mountain) uplift
Quaternary rocks
Muley Gulch
0
5
10 KILOMETERS

Figure 1 (facing page). Structural setting of South Park in relation to the Elkhorn and Williams Range faults and the Ancestral Rockies.

moderately east (fig. 1). In this segment, the hanging wall is comprised of a variety of Proterozoic rocks that structurally overlie a footwall of steeply folded to overturned Jurassic to Paleocene beds that include the South Park Formation. Folding accounts for much of the structural relief across this part of the deformational front. Actual fault displacement is hard to quantify, but we suggest that it is not much (<200–300 m). Displacement appears to lessen near the southern end of the fault exposure where older footwall rocks are exposed at the fault contact.

The downdropped South Park half-graben intervenes between the exposed southern branch of the Williams Range thrust at Georgia Pass and the Elkhorn fault (fig. 1). A young normal fault bounds the east side of the half-graben in northern South Park where it acts as the structural boundary between uplifted and downdropped areas. How and where the two branches of the Elkhorn connect across the graben, or if they even do, is the subject of interpretation. Most workers (for example, Barker and Wyant, 1976; Bryant and others, 1981a) directly connect the two branches across South Park by proposing a buried branch, or numerous ones, between the two exposed areas. Buried branches, which are attractive because of the alignment of the two segments, are feasible but they are hard to document and do not satisfy the basic Elkhorn-fault relations as understood in the two exposed areas. Where exposed, the Elkhorn consistently has Proterozoic rocks in the hangingwall to its east and Mesozoic to lower Tertiary strata or plutonic rocks in the footwall to its west (this is also true of the Williams Fork thrust to the north). Any buried branch that cuts across South Park would have to be entirely within the Mesozoic and Tertiary strata that are preserved in that graben, resulting in very little hangingwall/footwall distinction. This would locally change the basic character of the fault and require a corresponding local redefinition of its role as an uplift-defining structure. Other than the apparent desire to connect nearly aligned segments, there is no compelling justification for any buried connection since the geology of northern South Park is no better explained as a result. The obvious alternative is two discrete faults, the Williams Range thrust fault and the Elkhorn fault, whose displacements die along strike in the flanks of the broad open fold structure of northern South Park. This is our preferred interpretation. South of Muley Gulch, the southern branch is also inferred to die out, as only broad open folds have been identified in the southern parts of the quadrangle.

Thick conglomerate and breccia deposits of the South Park Formation (Txc) occur near the trace of the Elkhorn fault trace in the vicinity of Elkhorn Ranch. The deposits form low, wooded hills of modest exposure and they contain boulders so large that they can easily be mistaken for outcrops of basement rocks. Clasts, which are as large as 10 m or more in diameter, are chiefly light-colored granitic rocks that were probably derived almost exclusively from Middle Proterozoic unit Yg. The deposits rest unconformably on Proterozoic gneiss east of the Elkhorn fault and on the conglomerate member of the South Park Formation (Tsc) west of the fault. The underlying part of the South Park Formation dips steeply to vertically below the subhorizontal unconformity at the base of the conglomerate indicating considerable fault-related folding of the older unit prior to emplacement of the conglomerate and breccia. It is not clear whether, or to what extent, the Elkhorn fault displaced the conglomerate and breccia. The size of the boulders and near complete lack of bedding suggest the conglomerate and breccia originated as either large rock slides from a nearby high-relief source area or as highly fractured hangingwall rock that was emplaced just in front of the advancing thrust. Any high relief was probably the result of activity on the Elkhorn fault, but all evidence of it is gone today, if it ever existed at all. For this reason we prefer the fractured-hangingwall interpretation.

In figure 1 the position of the western edge of the Laramide uplift at the Elkhorn fault is shown relative to the west edge of the older Anasazi uplift. The edge of the Anasazi uplift is buried beneath central South Park (cross section *C–C′*). Pennsylvanian and Permian rocks are exposed along the west edge of the Bailey quadrangle and the older Paleozoic rock units are present a few kilometers west of the quad border, all forming a section that dips uniformly east. Thus, the uplift boundary lies east of this dipping section. However, between the Paleozoic exposures to the west and the Elkhorn fault to the east there is a zone 8–9 km wide where Upper Jurassic Morrison Formation is the oldest known rock unit above the Proterozoic basement, the entire Paleozoic rock section having been removed by erosion during growth of the Anasazi uplift. Clearly this part of the Elkhorn footwall, which extends north-northwest throughout central South Park, was within the area affected by Anasazi uplift and erosion. Because the contact is concealed, the nature of this ancient uplift boundary, whether structurally controlled or purely erosional, is not known.

Post-Laramide Cenozoic History in the Bailey Quadrangle

East Side of Bailey Quadrangle

By the close of the Laramide orogeny, during the early Eocene (about 50 Ma), debris eroded from the Laramide Front Range uplift formed a sedimentary apron, now largely eroded, that lapped onto the flanks of the range. By the end of the Eocene (about 34 Ma), a widespread erosion surface cut on Precambrian rock had formed across the Front Range (Epis and Chapin, 1975), due in part to the relatively stable base level, unusually warm climate, and deep weathering (Chapin and Kelly, 1997). The erosion surface generally had low relief, but locally subdued ridges and summits stood as much as a few hundred meters above it (Epis and others, 1980). Although absolute elevations are not known, there is no compelling reason to think that this erosion surface was particularly high in elevation, because there might not have been much difference in topographic relief between the present-day plains and mountains at the close of the Eocene. MacGinitie (1953) provided paleobotanical evidence from the Florissant fossil beds (≈34 Ma), approximately 10 km south of the quadrangle within the Front Range that suggested that elevation could not have been higher than 900 m (2,950 ft).

The present topographic relief along the eastern margin of the Front Range is due to post-Eocene erosion (Leonard and Langford, 1994), which removed 300–400 m of material from the Denver Basin area (Kelley and Chapin, 1995). This erosion occurred in response to profound, regional uplift that affected plains and mountains more-or-less equally (Kelley and Chapin, 1995). The present high elevations result chiefly from this late Cenozoic epeirogenic uplift.

West Side of Bailey Quadrangle

Upper Eocene, Oligocene, and Miocene rock units in the South Park area are chiefly ash flows, ash falls, and conglomerates. Some lacustrine beds are also present. Some of these units may have been widespread at one time, but they are now confined to discontinuous and isolated exposures.

Remnants of at least one of the ash flows, the Wall Mountain Tuff (Twm), are preserved on both sides of the trace of the Elkhorn fault, a strong suggestion that most of the relief associated with that structure was leveled by 36 Ma (McIntosh and Chapin, 2004) when the tuff erupted. The thickness of tuff is highly variable and contorted internal flow structures suggest that the ash piled up in paleovalleys where late-stage flow in the still-hot accumulations took place. The paleovalleys must have crossed the trace of the Elkhorn fault.

Tuffaceous lacustrine deposits of the Oligocene Antero Formation (Ta) are preserved in eastern and southern South Park. They are thin and poorly exposed equivalents of the Florissant lake beds to the east. The lakes formed where thick volcanic deposits dammed streams on the Eocene erosion surface (McGookey, 2002). Exposures along the southern quadrangle border near Hartsel are on average 100 m lower in elevation than the more northerly outcrops north of Muley Gulch. Assuming a single level lakebed, this suggests at least that much differential vertical tectonism over a distance of less than 15 km in this area since Oligocene time. Several post-Antero normal faults with northwest-southeast orientations are present in the area and may account for such an elevation difference.

Geomorphic evidence suggests Neogene to Quaternary tectonic activity within South Park and the Front Range. The Miocene gravel at Divide (Tdg) lies on the crest of the Rampart Range, east of Manitou Park, in the southeast corner of the quadrangle. This deposit contains clasts of volcanic rocks with a South Park provenance. This indicates that Manitou Park formed as a post-Miocene graben. Landslides, disturbed topography, lineaments, and anomalous drainage patterns within the Tarryall Mountains would also suggest plausible evidence for Neogene tectonic activity. The Chase Gulch fault has late Pleistocene displacement (Shaffer, 1980; Shaffer and Williamson, 1986; Kirkham and Rogers, 1981; Colman, 1985). These faults align with one to the south that has demonstrable Quaternary displacement southwest of Kenosha Pass along the Elkhorn fault, so deformation apparently has continued into the Quaternary Period within South Park.

Quaternary

Surficial deposits in the Bailey quadrangle record alluvial, mass-movement, glacial, and eolian processes during the Quaternary and late Neogene. Quaternary deposits and landforms in the quadrangle are the products of earth-surface processes during global climate-driven glacial-interglacial cycles during the past 1.8 million years. Global climatic cooling during the later part of the Pliocene continued into the Pleistocene and intensified after 900 ka (Clark and Pollard, 1998). The stratigraphic record suggests that there were at least 12 glaciations in the mountains of the Western United States during the Quaternary (Richmond and Fullerton, 1986b, chart 1). Pleistocene glacial deposits in Colorado and elsewhere in the Rocky Mountains are commonly correlated with Pinedale, Bull Lake, and pre-Bull Lake glaciations (Meierding and Birkeland, 1980; Pierce, 2004). Blackwelder (1915) named the Pinedale (last major) and Bull Lake (penultimate) glaciations for younger and older sets of moraines and glacial deposits on the eastern and western flanks of the Wind River Range, Wyo. Glacial deposits that predated the Bull Lake glaciation typically lack morainal form and have scattered surface boulders; they are locally preserved just beyond the outer limits of Pinedale and Bull Lake ice. These deposits have been identified in a few areas north of the quadrangle (Meierding and Birkeland, 1980).

Glacial deposits of pre-Bull Lake age are also locally exposed within the map area. They consist of till that underlies very subdued landforms about 2 km downstream along Tarryall Creek from subdued moraines of Bull Lake ages approximately 4 km northwest of Como, Colo. (Widmann and others, 2005). The till overlies poorly sorted boulder gravel with a silty sand matrix. Due to erosion and local burial by deposits of younger and more extensive glacial advances (Meierding and Birkeland, 1980) or glacial outwash, many of these older glacial deposits are difficult to distinguish. These older glacial deposits are included with younger tills in unit Qti. Glacial deposits of early Pleistocene age are especially likely to be buried by younger glacial deposits because cold (glacial)/warm (interglacial) climatic cycles prior to 900 ka (marine oxygen isotope stage, MIS 22) were of lower amplitude (lower global ice volume) and of much shorter duration (about 40 percent as long) than those after 900 ka (Clark and Pollard, 1998). Also, marine oxygen isotope records show only two glacial episodes (marine oxygen isotope stages MIS 12 and 16; about 424–475 ka and 621–675 ka, respectively; Lisiecki and Raymo, 2005) that were as severe (in terms of temperature and global ice volume) as those during the Bull Lake and Pinedale glaciations. This suggests that deposits of pre-Bull Lake glaciations prior to MIS 16 are likely to be less extensive than those of the Bull Lake and Pinedale glaciations. Bull Lake deposits in their type area in Wyoming are dated at about 170–120 ka (Sharp and others, 2003; Pierce, 2004).

Till and minor amounts of stratified drift of the Pinedale glaciation form well- preserved moraines that are widespread in the upper part of glaciated valleys of the Mosquito Range and near canyon mouths in South Park. Pinedale glacial deposits (Qtp) in Colorado are about 30–12 ka (Nelson and others, 1979; Madole, 1986; Schildgen and Dethier, 2000; Benson and others, 2004, 2005). Till and other ice-contact deposits of the Pinedale glaciation may locally include or overlie glacial deposits of early Wisconsin age (MIS 4, 70–55 ka; Lisiecki and Raymo, 2005), which are identified in a few areas of the Western United States (Pierce, 2004).

During the Bull Lake and Pinedale glaciations, glaciers in the quadrangle were as long as 5–9 km, and typically descended to elevations of about 3,000–3,200 m. These glaciers formed on the east side of the Continental Divide and descended canyons on the eastern flank of the Mosquito Range. Mount Logan along the North Fork of the South Platte River, along the northern boundary of the quadrangle, also supported small alpine glaciers. Glacial deposits have not been identified within the Platte River, Kenosha, and Tarryall Mountains, which are lower in elevation than the Mosquito Range and Mount Logan. Sharp-crested moraines produced by post-Pinedale glacial advances of Holocene and latest Pleistocene age are locally present within cirques along the western boundary of the quadrangle (Davis, 1988).

Snow lines during the Pleistocene in the Western United States were roughly 1,000 m lower than present (Porter and others, 1983). Fossil beetles near Denver (1,731 m), dated at 14,500 14C yr B.P., suggest that during full- or late-glacial climatic conditions, mean July temperatures were 10°–11° C colder than present, and mean January temperatures were 26°–30° C colder than present (Elias, 1996). Relict permafrost features in Wyoming suggest that temperatures could have been 10°–13° C colder than they are at present (Mears, 1981). Increased precipitation and vigorous freeze-thaw action likely accompanied expanded periglacial environments during glacial episodes, and would have promoted slope instability and intensified mass-movement processes in the Mosquito Range, the Front Range, and the hogback belt on the west side of the Colorado Piedmont. Much of the coarse debris, which forms features such as block fields and block streams on interfluves above and beyond the limit of glacial ice in the Mosquito Range and the Front Range, probably formed chiefly under periglacial conditions. Some of the landslide deposits in glaciated valleys formed after glaciers retreated and glacial ice no longer provided lateral support to weakly consolidated material on steep, unstable slopes. Increased infiltration of precipitation may have locally promoted deep-seated rock creep on steep mountain slopes in periglacial environments.

Streams draining from glaciers within the quadrangle produced broad, gravelly glacial outwash in mountain valleys and in South Park, particularly during times of significantly greater sediment yield during deglaciation (Church and Ryder, 1972). Some of the glacial outwash may be slightly younger than corresponding tills, because fluvial deposition lagged (perhaps by a few to several thousand years) the onset of the climatic change from glacial to interglacial climates (Church and Ryder, 1972; Hancock and Anderson, 2002). Glacial outwash deposits within South Park are mapped as intermediate (Qai) and young (Qay) alluvium of late middle Pleistocene and late Pleistocene respectively. These deposits grade up-valley to coeval glacial deposits.

Glacial outwash (Qay) and till of the Pinedale glaciation (Qtp) on and near the east flank of the Mosquito Range and coeval alluvium of non-glacial origin (Qay) in South Park are correlated with the Broadway Alluvium (Qb on Denver West quadrangle) in the Colorado Piedmont. Likewise, older glacial outwash (Qai) and till of the Bull Lake glaciation (Qtb) on and near the east flank of the Mosquito Range and coeval alluvium of non-glacial origin (Qai) in South Park are correlated with the Louviers Alluvium (Ql on Denver West quadrangle) (Scott, 1975; Madole, 1991). These correlations (table 1) are based chiefly on the morphology of surface soils formed in these deposits (Birkeland and others, 2003) and heights of glacial outwash and piedmont alluvial deposits above present streams. Recent cosmogenic dating supports these correlations (Schildgen and Dethier, 2000). About 50 km north of the map area, 10Be and 26Al ages of Pinedale (30–11 ka) and Bull Lake (≈130 ka) glacial outwash in Boulder Canyon east of Nederland (Schildgen and others, 2002) and their heights above stream level, support the concept that Pinedale outwash (8–12 m) is equivalent in age to Broadway Alluvium (Qb on Denver West quadrangle), and Bull Lake outwash is equivalent in age to Louviers Alluvium. Alluvial deposits of Holocene age are in present flood plains and form terrace deposits less than 5 m above present streams in the Colorado Piedmont. They are difficult to correlate with specific climatic episodes, but some may reflect past climatic conditions that were colder and possibly more moist (or due to more effective precipitation) than at present. These latter climatic episodes promoted glacial and (or) periglacial activity in the Front Range during the Holocene (Scott, 1975).

The depositional chronology, as well as the climatic (glacial or interglacial) and fluvial conditions that prevailed during the deposition of most of the pre-Louviers (pre-Bull Lake) alluvial deposits in the Colorado Piedmont near Denver, can only be inferred. Pre-Louviers alluvial deposits were transported and deposited by streams that headed in glaciated, as well as nonglaciated drainage basins in the Front Range. Many of these deposits probably accumulated chiefly during glacial episodes, particularly during maximum glaciation or

Table 1. Correlation of alluvial deposits along the western margin of the Colorado Piedmont near Denver, Colo. with alluvial deposits in South Park and glacial deposits in the Rocky Mountains. Modified from Kellogg and others (2008).

Deposits in Colorado Piedmont	Deposits in South Park	Age or age estimate (ka)	Correlative glaciation in Rocky Mountains
Post-Piney Creek Alluvium and Piney Creek Alluvium	Valley-floor alluvium (Qa)	0–4[a]	Minor post-Pinedale ice advances
Broadway Alluvium	Young alluvium (Qay)	12–30[b]	Pinedale
No known deposits	No known deposits	55–70[c]	Early Wisconsin
Louviers Alluvium	Intermediate alluvium (Qai)	120–170[b]	Bull Lake
Slocum Alluvium	Old alluvium (Qao)	240–390[d]	Pre-Bull lake
Verdos Alluvium older deposits	Old alluvium (Qao)	610–675[e]	Sacagawea Ridge
Rocky Flats Alluvium	No known deposits	1,400–2,000[f]	No known episode

[a]Age of alluvial deposits based on limited radiocarbon analyses (Scott, 1962; 1963a; Madole, 1976; Lindsey and others, 1998; Madole and others, 2005).

[b]Age of till and outwash of the Pinedale glaciation is based on radiocarbon and cosmogenic isotopic ages (Nelson and others, 1979; Madole, 1986; Schildgen and Dethier, 2000; Schildgen and others, 2002; Benson and others, 2004; 2005). Age of till and outwash of the Bull Lake glaciation is based on cosmogenic isotopic ages (Schildgen and Dethier, 2000; Schildgen and others, 2002; Sharp and others, 2003; Pierce, 2004).

[c]Age estimate is for marine oxygen isotope stage 4 (Lisiecki and Raymo, 2005).

[d]Age estimate derived from uranium-series dating (Madole, 1991; Kellogg and others, 2008).

[e]Age estimate for alluvial deposits based on stratigraphic position of 640-ka Lava Creek B tephra and tentative correlation with marine oxygen isotope stages (Kellogg and others, 2008).

[f]Age estimate derived from soil characterisitics and paleomagnetic data (Birkeland and others, 1996) and could be as old as 2 Ma (Birkeland and others, 2003; Riihimaki and others, 2006; Kellogg and others, 2008).

deglacial phases of glacial episodes, when climatic (glacial and periglacial) and fluvial conditions, as well as abundant sediment supply, promoted increased stream discharge and sediment load (Church and Ryder, 1972; Sinnock, 1981; Ritter, 1987; Madole, 1991). However, events unrelated to glaciation, such as stream capture and minor periods of cutting and filling unrelated to major climatic events (such as lateral migration of the South Platte River and its influence on tributary streams), likely accounted for deposition of some of these deposits (Ritter, 1987; Reheis and others, 1991).

Comparison of the isotopic ages for deposits of the Pinedale glaciation (30–12 ka) and Bull Lake glaciation (170–120 ka) with cold and warm climatic episodes of the marine oxygen isotope record (for example, Shackleton and Opdyke, 1973, 1976; Lisiecki and Raymo, 2005) suggest that outwash deposits of the Pinedale (Qtp) and Bull Lake (Qtb) glaciations and the correlative fluvial deposits in the Colorado Piedmont (Broadway Alluvium and Louviers Alluvium, respectively) were deposited chiefly during major cold climatic episodes, and in part during succeeding warm climatic episodes. These relations suggest that pre-Louviers alluvial deposits in the Colorado Piedmont may have accumulated under somewhat similar climatic conditions.

Younger (topographically lower) and older (topographically higher) deposits of Slocum Alluvium (Qs) are locally present near the northeast corner of the quadrangle. These deposits are about 20 and 30 m, respectively, above flood plains of Plum Creek and the South Platte River. The younger deposits may have accumulated between about 300 and 220 ka and older deposits between about 390 and 320 ka (Kellogg and others, 2008, table 1).

Younger (topographically lower) and older (topographically higher) deposits of Verdos Alluvium (Qv) are also locally present near the northeast corner of the quadrangle. These deposits are about 55 and 75 m, respectively, above the present flood plain of Plum Creek. The age of older deposits of Verdos Alluvium is fairly well constrained, because these deposits locally overlie, contain, or are overlain by water-laid deposits of the Lava Creek B tephra (640 ka) (Machette, 1975; Machette and others, 1976; Van Horn, 1976), which was deposited when glaciers were retreating, during the transition from glacial to interglacial climatic conditions (Dethier and others, 2001; Fullerton, D.S., oral commun., 2006). This indicates that older deposits of Verdos Alluvium were deposited near the end of a major cold climatic episode during MIS 16 (675–621 ka; Lisiecki and Raymo, 2005), and possibly in part during the early part of MIS 15. These deposits are similar in age to till and outwash of the Sacagawea Ridge glaciation near the type area for this glaciation on the eastern flank of the Wind River Range, Wyo., where water-laid Lava Creek B tephra is present in the top of the outwash (Jaworowski, 1992; Chadwick and others, 1997). The stratigraphic position of the water-laid tephra with respect to older pediment and fluvial deposits of the Verdos Alluvium (Qv) suggests that the older pediment deposits are younger than the older fluvial deposits (Machette, 1975). The younger deposits may have accumulated between about 475 and 410 ka (Kellogg and others, 2008, table 1). Younger deposits of the Verdos Alluvium may be correlative in part with shoreline and nearshore deposits that formed during a high stand of Lake Alamosa in the San Luis Basin in southern Colorado at about 450 ka (Machette and others, 2007). If the age estimate for younger deposits of Verdos Alluvium is correct, it suggests limited fluvial deposition during cold (glacial) climatic conditions of marine oxygen isotope stage 12 (about 475–425 ka) in the Colorado Piedmont near Denver. Alternatively, younger deposits of Verdos Alluvium may locally include alluvium deposited during marine oxygen isotope stage 14 (about 570–533 ka) as well as during stage 12.

Cosmogenic dating (on 10Be and 26Al) of alluvial-fan deposits that are typically ≤5 m thick (Knepper, 2005) that constitute the upper part of the Rocky Flats Alluvium (QNr) at Rocky Flats indicates that they date from about 1.5 Ma (Dethier and others, 2001) or about 1–2 Ma (Riihimaki and others, 2006). However, at the Rocky Flats type section (Scott, 1960; Birkeland and others, 1996), the buried soil formed on underlying valley-fill deposits, as much as 25 m thick (Knepper, 2005), suggesting that the lower part of the unit may be much older. Morphologic and paleomagnetic properties of buried soils at a site about 3 km south of the Rocky Flats plant support the cosmogenic ages and suggest that the Rocky Flats Alluvium dates from at least 1.6–1.4 Ma (Birkeland and others, 1996), and possibly is about 2 m.y. old (Birkeland and others, 2003). Although the Coal Creek drainage basin (the source of the Rocky Flats Alluvium on Rocky Flats) was never glaciated, the Rocky Flats Alluvium may have been deposited during one or more glacial episodes. Considering the age constraints for the Rocky Flats Alluvium and the fact that no evidence has been found for a major glaciation in the United States between 1.5 Ma and 900 ka (Richmond and Fullerton, 1986a; 1986b, chart 1), the Rocky Flats Alluvium may have been deposited after 2.5 Ma but prior to 1.5 Ma, the onset of major northern-hemisphere glaciations (Shackleton and others, 1984; Prell, 1984; Thompson, 1991; Ravelo and others, 2006).

Eolian deposits are widespread east of the mountain front in the Colorado Piedmont northeast of the quadrangle (Trimble and Machette, 1979). Thin, unmapped deposits locally mantle many of the older alluvial surfaces and deposits in South Park. Age assignments, spatial distribution, and downwind fining of the particle size of eolian sand and loess in the Colorado Piedmont suggest a close relation between the genesis of these deposits and active aggradation of sparsely vegetated flood plains, chiefly during the Pinedale and Bull Lake glaciations. Some of the loess, and possibly some of the eolian sand northeast of the quadrangle, were derived directly from bedrock sources (Scott, 1962; Madole, 1995; Aleinikoff and others, 1999). Probably much of the loess within the map area was deposited during two episodes during the Pinedale glaciation (about 20–14 ka and 13–10 ka; Muhs and others, 1999). Some accumulation may have occurred during the Bull Lake glaciation (about 150 ka; Forman and others, 1995). Episodes of loess deposition probably were coeval with episodes of flood plain aggradation.

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