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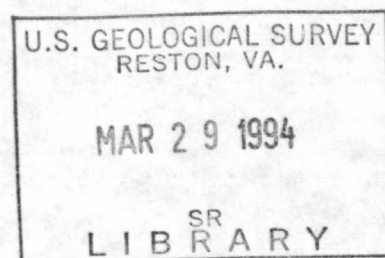
U.S. GEOLOGICAL SURVEY

PRELIMINARY SURFICIAL GEOLOGIC MAP OF THE ROCKY FLATS PLANT AND VICINITY,  
JEFFERSON AND BOULDER COUNTIES, COLORADO

by

RALPH R. SHROBA<sup>1</sup> AND PAUL E. CARRARA<sup>1</sup>

Open-File Report 94-162

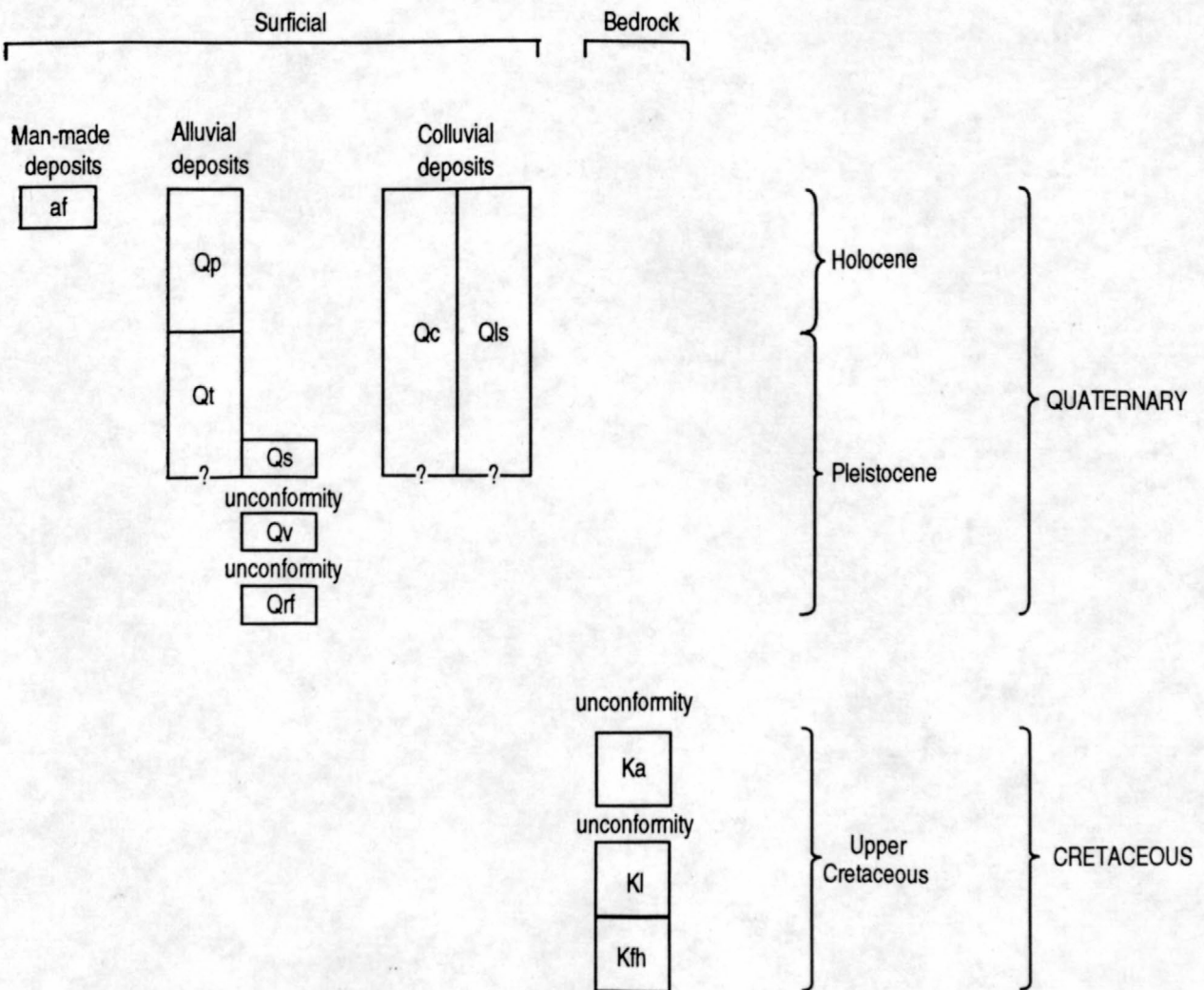


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Technical work for this report was funded under USGS DOE Interagency Agreement DE-A134-93RF00674. However, any findings or opinions expressed herein are solely those of the USGS.

<sup>1</sup> Denver, Colorado

# CORRELATION OF MAP UNITS



## DESCRIPTION OF MAP UNITS

[Surficial deposits shown on the map are estimated to be at least 1 m thick. Thin, discontinuous artificial fill (af) and colluvium (Qc) were not mapped. Also not mapped is a thin (about 50 cm) layer of pebbly, clayey, sandy silt, which locally mantles the Slocum Alluvium (Qs) and older alluviums in the eastern third of the map area. This layer is weathered and may be comprised in part of pre-Louviers (middle Pleistocene) loess that contains clasts from the underlying gravelly alluvium. It may correlate with the older loess of Scott (1963). The contacts between colluvium (Qc) and old landslide (Qls) deposits are approximate, because these deposits commonly lack distinct topography. Most of the surficial deposits in the map area are poorly exposed, except for the Rocky Flats Alluvium (Qrf) adjacent to clay and gravel pits in the western part of the map area, and Verdos Alluvium (Qv) along Indiana Street at the eastern margin of the map area. Post-Piney Creek alluvium and Piney Creek Alluvium (Qp) and terrace deposits (Qt) were not subdivided because they are of limited areal extent and lack sufficient exposures to identify age-related properties. Age assignments for surficial deposits are based chiefly on height above stream level, degree of post-depositional modification of original surface morphology, and degree of soil development. Soil-horizon designations are those of the Soil Survey Staff (1975) and Guthrie and Whitty (1982). Many of the surficial deposits are calcareous and contain different amounts of secondary calcium carbonate; stages of secondary calcium carbonate morphology are those of Gile and others (1966). Grain sizes given for surficial deposits are based on visual estimates and follow the modified Wentworth scale (American Geological Institute, 1982). Divisions of Pleistocene time correspond to those of Richmond and Fullerton (1986). In map-unit descriptions of surficial deposits, the term clasts refers to the fraction that is greater than 2 mm in size, whereas the term matrix refers to the fraction that is less than 2 mm in size. Dry colors of the less than 2 mm-size fraction of the surficial deposits were determined by comparison with the Munsell Soil Color Charts (Munsell Color, 1973). Most of the geologic contacts, vegetation boundaries, springs, and seeps on this map were transferred from 1:9,000-scale, false-color, infrared aerial photographs, taken on July 1, 1989, using a Kern PG-2 stereoplotter. Some of the contacts of the Arapahoe and Laramie Formations and all of the bedrock unit descriptions are modified in part from Hurr (1976) and Stoller and Ebasco (1992). The topography as shown on this map is inaccurate north and south of the Rocky Flats Plant boundary; geologic contacts in these areas were adjusted to conform to the inaccurate topography. All of the streams and irrigation ditches in the map area are ephemeral.]

## **Man-made deposits--Earth, rock fragments, and refuse placed in fills and dumps**

- af **Artificial fill (latest Holocene)**-- Unit consists of compacted and uncompacted fill material composed of varying amounts of sand and finer material, rock fragments, and locally refuse. Unit includes road and railroad embankments, earth dams, and other engineered fills, as well as compacted and uncompacted landfills, and spoil piles along some of the irrigation ditches. Large areas of artificial fill on the north side of the south intercept ditch and at the head of No Name Gulch are landfills. Large areas of artificial fill next to the gravel and clay pits, near the western boundary of the map area, are mine dumps composed of uncompacted surficial material and rock fragments. Unit locally includes small areas of Rocky Flats Alluvium (Qrf) and other surficial deposits. Thickness commonly less than 3 m; some of the earth dams and landfills are greater than 10 m thick

## **Alluvial deposits--Clay, silt, sand, and gravel in flood plains, stream channels, and terraces along Rock Creek, Walnut Creek, Woman Creek, and their tributaries, and in channel-fill and pediment deposits beneath the Slocum, Verdos, and Rocky Flats surfaces**

- Qp **Post-Piney Creek alluvium and Piney Creek Alluvium, undivided (Holocene)**-- In the western part of the map area, unit commonly consists of clast-supported, slightly bouldery, pebble and cobble gravel in a dark-gray sand matrix. Fines downstream. In the eastern part of the map area, unit commonly consists of slightly pebbly, grayish-brown, silty sand to sandy, clayey silt in the upper part and poorly sorted, clast-supported, slightly cobbly, pebble gravel in a light-yellowish-brown, clayey, silty sand matrix in the lower part. Clasts are mostly subangular quartzite and a minor amount of subrounded sandstone that were derived from older Quaternary deposits. Post-Piney Creek alluvium lacks secondary calcium carbonate, whereas Piney Creek Alluvium contains stage I carbonate veinlets and locally one or more buried soil A horizons, about 10 cm thick. The map unit locally contains abundant remains of *Bison bison*, but no definite Pleistocene fossils (Malde, 1955). Bones of a large vertebrate were found in the unit along Walnut Creek, near the eastern margin of the map area. The post-Piney Creek alluvium forms stream channels and flood plains that have well preserved bar-and-channel morphology. The Piney Creek Alluvium forms low terraces about 1-2 m above stream level that lack or locally have poorly preserved bar-and-channel morphology. The Piney Creek Alluvium may contain expansive clay derived from Upper Cretaceous claystone bedrock and locally may have high swell potential (Hart, 1974). Low lying areas are prone to periodic flooding. The valley-side portion of some of the terraces is locally mantled by colluvium (Qc) and landslide (Qls) deposits. Thickness about 1-5 m; average thickness about 3 m (EG&G, 1991; Appendix B).
- Qt **Terrace alluvium, undivided (late and middle Pleistocene)**-- In the western quarter of the map area, unit commonly consists of clast-supported, slightly bouldery, pebble and cobble gravel in a light-yellowish-brown to reddish-brown sand matrix. Unit locally contains beds and lenses of sandy, pebble gravel and pebbly sand. In the eastern three-quarters of the map area, unit is chiefly a slightly cobbly, pebbly, light-grayish-brown to light-reddish-brown, silty sand to clayey silt. Clasts are mostly subangular quartzite. Unit forms small terraces and terrace remnants, about 2.5 to 10 m above stream, that lack bar-and-channel morphology and are locally mantled by a thin layer of colluvium (Qc). Terrace deposits in the western quarter of the map area are probably composed mostly of Slocum Alluvium, about 240 ka (thousand years; Madole, 1991). Those in the eastern three-quarters of the map area are younger and are probably composed mostly of Broadway and Louviers Alluviums. These younger alluvial deposits form terraces and terrace remnants throughout the Denver area (Trimble and Machette, 1979) and range in age from about 10 or 12 to about 140-150 ka. The Broadway correlates with the Pinedale glaciation (about 10 or 12 to 35 ka) and the Louviers with the Bull Lake glaciation (about 140-150 ka) (Scott, 1962, 1963; Van Horn, 1976; Madole, 1991). Thickness probably about 3-6 m



- Qs Slocum Alluvium (middle Pleistocene)**-- Unit is poorly exposed, but appears to consist mainly of clast-supported, cobbly pebble gravel in a brown to reddish-brown sand matrix, sandy pebble gravel, and pebbly sand. Clasts are mostly subangular quartzite that are as long as 25 cm. Unit forms small remnants of valley fills or pediment deposits (?) that are about 10-20 m above Woman Creek in the southeastern part of the map area. Much of the original deposit has been removed by erosion. Deposit is about 240 ka (Madole, 1991). Thickness probably about 2-3 m
- Qv Verdos Alluvium (early middle Pleistocene)**-- Unit commonly consists of beds and lenses of poorly sorted, clast-supported, cobbly pebble gravel in a brown to reddish-brown sand matrix; poorly sorted to moderately well sorted, clast- and matrix-supported, sandy pebble gravel; and pebbly, silty sand. Clasts are mostly subangular quartzite (table 1) that are reworked from the Rocky Flats Alluvium (Qrf). Unit forms remnants of valley fills and pediment deposits that are about 35-45 m above stream level in the eastern part of the map area and about 30 m above stream level near the northwestern corner of the map area. The upper part of the unit contains a thin, clayey, soil argillic B (Bt) horizon that overlies a stage III K horizon, about 50-80 cm thick. South of the map area near Ralston Reservoir (fig. 1), the Bt horizon is about 110 cm thick and contains 17-29 percent clay in the less than 2 mm-size fraction. It overlies a discontinuous, stage III-IV K horizon that is as much as 60 cm thick and contains 26-93 percent calcium carbonate in the less than 2 mm-size fraction (Machette and others, 1976a). Beds and lenses of the 620-ka Lava Creek B volcanic ash are present in the upper part of the unit at a few localities in the Denver area (Hunt, 1954; Van Horn, 1976). Thickness about 1-4 m
- Qrf Rocky Flats Alluvium (early Pleistocene)**-- In the western part of the map area, unit commonly consists of a poorly sorted, clast-supported, slightly bouldery, cobble and pebble gravel in a light-brown to light-red, clayey sand matrix (fig. 2). Unit also contains beds and lenses of sandy pebble gravel, pebbly silty sand, and cobbly and pebbly sandy clay. In the eastern part of the map area, unit commonly consists of thin (5-90 cm) beds and lenses of poorly sorted, clast- and matrix-supported, white to pink, sandy pebble gravel, pebbly sand, and silty sand. Clasts are commonly subangular quartzite (table 1) that were derived from Coal Creek Canyon (fig. 1). Claystone pebbles are locally present in the lower 50 cm of the unit. Some of the deposits contain angular to subrounded sandstone clasts that were derived from nearby outcrops of either the Laramie Formation (Kl) or the Fox Hills Sandstone (Kfh). Quartzite boulders in the western part of the map area are as large as 50x70x120 cm and some of them appear to be abraded by wind erosion. Granitic and gneissic clasts that are rich in mafic minerals are partially to completely disintegrated; some of the sandstone clasts are partially disintegrated. Much of the unit is probably of alluvial origin; however, many of the fine-grained deposits that contain scattered sandstone clasts and few if any quartzite clasts, in the western part of the map area, may be of debris-flow origin. Unit forms a large fan-shaped pediment deposit that locally overlies valley-fill deposits. In the eastern part of the map area, the top of the pediment deposit is about 45-70 m above Rock, Walnut, and Woman Creeks. In the western part of the map area, the top of the unit contains a thick (80-150 cm), clay-rich, soil argillic B (Bt) horizon that overlies and locally contains a discontinuous, stage III-IV soil K horizon, as much as 50 cm thick. In the eastern part of the map area, the Bt horizon is thin (about 30 cm) and overlies a strongly developed stage III-IV K horizon, which is greater than 135 cm thick. Abundant drill-hole data (EG&G, 1991; Appendix B) indicates that thicknesses are commonly about 1-10 m where pediment deposits overlie Upper Cretaceous bedrock and are about 10 to greater than 30 m where these deposits overlie valley-fill deposits.

**Colluvial deposits--Clay, silt, sand, and gravel on valley sides that were mobilized, transported, and deposited by gravity and sheet erosion**

- Qc Colluvium, undivided (Holocene to middle Pleistocene)--** Unit commonly consists of dark-gray to light-reddish-brown, silty sand, sandy silt, clayey silt, and silty clay that contain a minor amount of pebbles and cobbles. Unit locally includes clast- and matrix-supported, bouldery to pebbly gravel in a silty sand matrix. Deposits derived mostly from the Arapahoe (Ka) and Laramie (Kl) Formations commonly contain more silt and clay than those derived mostly from the Fox Hills Sandstone (Kfh) and surficial deposits, such as the Rocky Flats Alluvium (Qrf). Deposits derived from claystone of the Arapahoe and Laramie contain expansive clay (Van Horn, 1976; Shroba, 1982) and locally have high swell potential (Hart, 1974). Typically unsorted to poorly sorted and unstratified to poorly stratified. Clasts are typically subangular and subrounded; their lithologic composition reflects that of the bedrock and surficial deposits from which they were derived. The unit locally includes sheetwash, soil-creep, and landslide (Qls) deposits that are too small to map separately or that lack distinctive surface morphology and could not be identified in the field or on aerial photographs. Thickness probably about 1-5 m
- Qls Landslide deposits (Holocene to middle Pleistocene)--** Unit commonly consists of a dark-gray to light-reddish-brown, heterogeneous mixture of unsorted and unstratified surficial material and rock fragments in a wide range of sizes that were moved downslope by gravity. The unit includes earth flows, earth slumps, debris flows, debris slumps, rock-block slides, and complex landslides (Varnes, 1978). Deposits derived mostly from the Arapahoe (Ka) and Laramie (Kl) Formations commonly contain more silt and clay than those derived mostly from surficial deposits, such as the Rocky Flats Alluvium (Qrf). Deposits derived from claystone of the Arapahoe and Laramie contain expansive clay (Van Horn, 1976; Shroba, 1982) and locally have high swell potential (Hart, 1974). The lithologic composition of the clasts reflects that of the bedrock and surficial deposits from which the landslides were derived. Young landslide deposits are commonly bounded upslope by crescentic headwall scarps and downslope by lobate toes. Some of the landslide deposits are subject to sheetwash and soil creep. Unit locally includes small areas of post-Piney Creek alluvium and Piney Creek Alluvium (Qp) and colluvium (Qc). Thickness probably 3-10 m; maximum thickness about 30 m












**Bedrock-- Claystone, siltstone, sandstone, conglomerate, and coal that were deposited in marine and continental environments**

**Ka Arapahoe Formation (Upper Cretaceous)--** Unit commonly consists of light-olive-gray to black, massive to laminated claystone and silty claystone; light-gray to light-orange-brown, thin, discontinuous, silty, fine-grained sandstone; and minor light-gray to olive-gray, lenticular, channel-fill deposits that consist of medium- to coarse-grained sandstone and very poorly sorted, massive to trough crossbedded, conglomeratic sandstone. The lower half of the Arapahoe contains more sandstone than the upper half. Medium- to coarse-grained and conglomeratic sandstone is common at and near the base of the Arapahoe. This sandstone has a distinct composition, which consists chiefly of well rounded, frosted quartz grains and minor amounts of chert, ironstone, and volcanic-rock fragments. The rock fragments in the conglomeratic sandstone are mostly granule and pebble size, but some of the claystone fragments that were eroded from the underlying Laramie Formation (Kl) are locally as much as 75 cm in diameter. Deformed beds that may have been produced by slumping contemporaneous with deposition and hard ironstone beds, lenses, and concretions are locally present. Imprints of leaves as well as woody and carbonaceous material are locally common in thinly interlayered sandstone and claystone. Montmorillonite or mixed-layer illite-montmorillonite is the main clay mineral in the claystone of the Arapahoe, along with minor amounts of illite and kaolinite (Hurr, 1976; Shroba, 1982). Claystone of the Arapahoe has low to very high swelling pressures (about 15-345 kN/m<sup>2</sup>; Shroba, 1982), probably due in part to varying amounts of expansive clay. The Arapahoe unconformably overlies the Laramie Formation. The Arapahoe was previously included with and mapped as Laramie (Spencer, 1961; Van Horn, 1957, 1976). Thickness decreases from about 120-150 m near Golden and Broomfield (fig. 1). (Machette, 1977; Van Horn, 1976) to about 80 m (Hurr, 1976) or less (Stoller and Ebasco, 1992) in and near the map area

**Kl Laramie Formation (Upper Cretaceous)--** The upper part of the unit commonly consists of olive-gray to moderate-yellowish-brown, massive claystone that is interlayered with laminated silty and sandy claystone and thin (about 0.5-1.2 m) beds of light-olive-gray to dark-yellowish-orange, lenticular, very fine to fine-grained, silty sandstone, dark-gray to black carbonaceous claystone, and black subbituminous coal. The claystone locally contains scattered ironstone concretions. Deformed beds are locally present near the top of the unit. The lower part of the unit commonly consists of light-olive-gray to dark-yellowish-orange, thin to massive, very fine to medium-grained, moderate to well cemented sandstone and light-olive-gray to yellowish-orange, massive claystone that is interlayered with beds (about 0.2-3.4 m thick) of laminated siltstone, silty claystone, lenticular sandstone, and discontinuous coal. Resistant sandstone in the lower part of the Laramie forms hogbacks that extend from south of Golden northward to Marshall (Van Horn, 1972; Hurr, 1976). Coal has been mined from the Laramie at the Capitol Mine, in the southwestern part of the map area, and near the towns of Leyden, Superior, Louisville, and Lafayette (fig. 1) (Colton and Lowrie, 1973). Clay has been mined from the lower part of the Laramie in the western part of the map area, probably for brick, tile, and sewer pipe (Hansen and Crosby, 1982). Clay minerals in the claystone are mostly kaolinite and lesser amounts of montmorillonite and illite (Gude, 1950). Claystone of the Laramie has low to very high swelling pressures (about 60-295 kN/m<sup>2</sup>; Shroba, 1982), probably due in part to varying amounts of expansive clay. The Laramie conformably overlies the Fox Hills Sandstone (Kfh). Thickness of the upper part of the unit about 90-190 m; of the lower part of the unit about 45-100 m



**Kfh Fox Hills Sandstone (Upper Cretaceous)**-- The upper half of the unit is thick-bedded to massive and planar laminated to crossbedded, fine- to medium-grained, feldspathic sandstone. The lower half of the unit commonly consists of light-olive-gray to yellowish-gray, thinly bedded, friable, silty, very fine to medium-grained, feldspathic sandstone and a minor amount of grayish-olive, silty claystone and sandy siltstone. Sandstone in lower half of the unit is laminated to thinly bedded and locally contains trace fossils and iron-stained calcareous concretions as much as 60 cm in diameter. Exposed sandstone is white to dark-yellowish-orange, displays polygonal fracture patterns, and commonly form ledges and cliffs. The Fox Hills conformably overlies and interfingers with the underlying Pierre Shale. Kaolinite and montmorillonite or mixed-layer illite-montmorillonite are the main clay minerals in the claystone of the Fox Hills (Shroba, 1982). Claystone of the Fox Hills has low to very high swelling pressures (about 60-295 kN/m<sup>2</sup>; Shroba, 1982), probably due in part to varying amounts of expansive clay. Thickness commonly about 12-27 m

-  Contact
-  Strike and dip of beds
-  20 Clast identification site (see table 1)
-  Scarp of young landslide
-  Shallow (40 cm), closed depression-- near northwestern corner of map area
-  Rectangular water bodies
-  Spring identified in the field
-  Spring or seep identified on aerial photographs
-  Areas and lines of vegetation identified on aerial photographs that may be associated with springs and seeps
-  Boundary of gravel and clay pits
-  Mine shaft



**Table 1. Lithology of clasts in the Rocky Flats and Verdos Alluviums in and near the map area.**

[Values are in percent for clasts about 1-15 cm in diameter; about 125-140 clasts were identified at each locality. Field localities are shown on map and fig. 1.]

| Map unit               | Rocky Flats Alluvium |     |     | Verdos Alluvium |     |     |     |
|------------------------|----------------------|-----|-----|-----------------|-----|-----|-----|
| Field locality         | 14                   | 42  | 43  | 10              | 13  | 20  | 21  |
| Quartzite              | 72                   | 77  | 70  | 89              | 81  | 83  | 81  |
| Granite and gneiss     | 13                   | 12  | 21  | 5               | 9   | 4   | 4   |
| Sandstone <sup>1</sup> | 8                    | 5   | 2   | 3               | 1   | 5   | 10  |
| Schist                 | 4                    | 2   | 2   | 0               | 0   | 2   | 0   |
| Pegmatite              | 1                    | 2   | 5   | 3               | 4   | 2   | 2   |
| Vein quartz            | 2                    | 2   | 0   | 0               | 5   | 4   | 3   |
| Total                  | 100                  | 100 | 100 | 100             | 100 | 100 | 100 |

<sup>1</sup> Some of the deposits of Rocky Flats Alluvium at field locality 41 (map and fig. 1) contain 100 percent sandstone (based on visual estimates).

## Discussion

### Rocky Flats Alluvium

Rocky Flats is a prominent upland surface, about 25 km<sup>2</sup> in area, along the western margin of the Colorado Piedmont between Coal and Leyden Creeks (fig. 1). The surface is fan shaped with its apex at the mouth of Coal Creek Canyon, at an altitude of about 1,980 m, 3 km west of the map area. North of the mouth of Coal Creek Canyon, the Rocky Flats surface extends about 6 km to the Boulder-Jefferson County line. To the south, the surface is bounded by Leyden Creek. The gradient of the Rocky Flats surface ranges from about 30 m/km near its apex, to about 12-15 m/km near its eastern margin, 6-9 km to the east. The eastern part of the surface and the underlying alluvium have been dissected as much as 70 m by Rock, Walnut, and Woman Creeks. This dissection has produced a series of digitate promontories at altitudes of about 1,800-1,850 m that extend northeastward and eastward from the relatively smooth, western part of the surface, which is cut by a few shallow drainages. The surface locally has numerous, low, gravelly mounds that have been attributed to burrowing by pocket gophers (Murray, 1967). Near the western margin of the map area, the surface is characterized by very subdued bar-and-channel morphology that is visible on the aerial photographs, due primarily to slight differences in the vegetation. The bar-and-channel morphology probably dates from the time of deposition of the Rocky Flats Alluvium and is difficult to distinguish in the field, due to its low relief. The Rocky Flats Plant, established in 1952, is near the eastern margin of the Rocky Flats surface.

The Rocky Flats Alluvium was named by Scott (1960) for the oldest and highest, widespread Pleistocene alluvium in the Denver area. This alluvium was interpreted by Scott (1960) to have been deposited as a broad veneer on a pediment surface. Remnants of this once extensive alluvial surface are common in the Colorado Piedmont along the mountain front and along the South Platte and Arkansas Rivers. The larger remnants are along the western margin of the Colorado Piedmont adjacent to valleys that head in unglaciated areas, such as Coal Creek Canyon. Most of the coarse gravel deposits in and near the mouths of unglaciated valleys, such as the Rocky Flats Alluvium, probably accumulated during glacial times (Madole, 1991). The type locality of the Rocky Flats Alluvium is in an abandoned gravel pit on the southeastern margin of Rocky Flats (NW 1/4, SW 1/4, sec. 23, T. 2 S., R. 70 W.), about 1 km south of the map area (fig. 1). Here, Scott (1960) described a sheet of reddish-brown, poorly sorted, stony coarse sand, 3-12 m thick, which unconformably overlies a pediment surface cut on bedrock.

The age of the Rocky Flats Alluvium can be inferred from its geomorphic relationships with nearby younger and older alluviums. The Rocky Flats Alluvium is considered to be early Pleistocene in age because it is about 25-30 m higher and, therefore, older than the early middle Pleistocene Verdos Alluvium, which contains the 620-ka Lava Creek B ash (Malde, 1955; Scott, 1960, 1963; Van Horn, 1976; Madole, 1991). The Rocky Flats Alluvium is about 15 m lower than a small deposit of pre-Rocky Flats alluvium, about 0.6 km west of the map area, which is considered to be of early Pleistocene age (Van Horn, 1976).

The soil that is formed in the upper part of the Rocky Flats Alluvium is one of the most strongly developed soils in the Colorado Piedmont (Machette and others, 1976b). In the western part of the map area, the soil has a clay-rich, reddish-brown to dark-red, prismatic, soil argillic B (Bt) horizon, about 80-150 cm thick. This horizon overlies and locally contains a discontinuous, calcium carbonate-rich, soil K horizon, as much as 50 cm thick, that has stage IV carbonate morphology in the upper part (5 cm) and stage III morphology in the lower part. Translocated clay, expressed as reddish-brown clay films in the Bt horizon and the underlying alluvium, extends to depths of greater than 4 m below the ground surface. In the eastern part of the map area, the Bt horizon is much thinner (about 30 cm) and overlies a strongly developed K horizon, which is greater than 135 cm thick. The upper part (120 cm) of this K horizon has stage IV carbonate morphology and the lower part has stage III morphology. At the type locality of the Rocky Flats Alluvium, about 1 km south of the map area (fig. 1), the upper 2.5 m of the alluvium contains two K horizons, with stage III and IV carbonate morphology, that are overlain, separated, and underlain by moderately to strongly developed Bt horizons (Machette and others, 1976a). Near-surface Bt horizons in the map area commonly contain about 35-60 percent clay in the less than 2 mm-size fraction (Price and Amen, 1983). The two K horizons at the type locality contain as much as 86 and 94 percent calcium carbonate in the less than 2 mm-size fraction (Machette and others, 1976a).

The Rocky Flats Alluvium is locally much thicker than the 0.3-15 m reported by Malde (1955) and the 3-12 m reported by Scott (1960; 1963). Abundant drill-hole data for the area near the Rocky Flats Plant buildings (EG&G, 1991; Appendix B), shallow seismic refraction and electrical resistivity measurements near Rocky Flats Lake (fig. 1) (Ackermann, 1974), and several shallow trench excavations south and east of the plant buildings (Dames and Moore, 1981) indicate that the bedrock surface beneath the Rocky Flats Alluvium is very irregular. Depths to bedrock are commonly about 1-10 m, but are locally as much as 30 m or more. Irregularities are not uncommon on pediment surfaces, despite the even surface of the overlying gravel veneer. The downslope cross sections of a pediment surface are generally smooth, but cross sections normal to the pediment surface show paleochannels, some of which are 24 m or more deep (Pillmore and Scott, 1976). This situation exists in the area near the plant buildings (EG&G, 1991; Appendix B).

A possible interpretation of this drill-hole, seismic, and trench data is as follows. Ancestral Coal Creek may have had one or more episodes of downcutting and valley development, probably during interglacial times, in response to decreases in runoff and sediment yields. Each of these episodes of downcutting and valley development were followed by episodes of valley filling, probably during glacial times, when lower treeline and expanded periglacial activity promoted an increases in runoff and sediment yields (Church and Ryder, 1972; Madole, 1991). The last phase of valley filling may have been followed by one or more episodes of stable base level, during which one or more extensive pediment surfaces were cut on the bedrock between the paleovalleys and on the intervening valley-fill deposits in the paleovalleys. In areas where the Rocky Flats Alluvium consists only of pediment deposits it is commonly about 1-10 m thick, and where the alluvium consists of pediment deposits over valley-fill deposits it is about 10 to greater than 30 m thick. More drill-hole, geophysical, and trench data would be needed for the rest of the Rocky Flats surface in order to decipher its complex geomorphic history.

Quartzite is the major clast component in the Rocky Flats Alluvium (table 1). The quartzite clasts were derived from the Coal Creek quartzite, which is exposed for several kilometers in the lower part of Coal Creek Canyon west of the map area (fig. 1). The Coal Creek quartzite is a dense, very hard, well bedded, commonly white to light-gray, locally micaceous, fine- to coarse-grained quartzite and conglomeratic quartzite of Early Proterozoic age (Wells, 1967). Clasts derived from this quartzite are commonly subangular. Many of the quartzite clasts in the Verdos Alluvium and younger surficial deposits were probably derived from the Rocky Flats Alluvium.

Other components of the Rocky Flats Alluvium are granitic and gneissic clasts (table 1) derived from rocks of Early Proterozoic age that are exposed in Coal Creek Canyon. The granitic clasts are derived from the Boulder Creek Granodiorite and a slightly younger quartz monzonite (Trimble and Machette, 1979). The Boulder Creek Granodiorite is a mottled black and white, medium- to coarse-grained, foliated granodiorite (Wells, 1967). The quartz monzonite is a light-brown to gray, fine-grained, foliated rock that contains scattered biotite and muscovite flakes (Wells, 1967). Gneissic clasts were derived from outcrops of a gray, medium-grained, foliated gneiss, containing foliated mica schist, exposed in the lower part of Coal Creek Canyon (Wells, 1967).

Minor clast components of the Rocky Flats Alluvium include sandstone, schist, pegmatite, and vein quartz (table 1). The sandstone clasts are derived mainly from the Dakota Sandstone of Cretaceous age, the Lyons Sandstone of Permian age, and arkosic, fine- to coarse-grained sandstone and conglomeratic sandstone of the Fountain Formation of Pennsylvanian and Permian age, which are exposed along the mountain front, west of the map area. In addition, a minor amount of the sandstone clasts was locally derived from the Laramie Formation and the Fox Hills Sandstone. The schist is derived from either the foliated mica schist in the gneissic rocks or from a fine-grained, well foliated, mainly biotite and muscovite schist exposed near the mouth of Coal Creek Canyon (Wells, 1967). Pegmatite and vein quartz were probably derived from minor bodies that intrude the Proterozoic rocks west of the mountain front.



Although much of the Rocky Flats Alluvium appears to be alluvium, some of the deposits in this unit may be debris flows. Likely candidates are the thin beds and lenses of cobbly and pebbly silty clay. The scattered sandstone clasts in these deposits were derived from nearby outcrops of Laramie Formation and Fox Hills Sandstone. Much of the clay in these deposits may be derived chiefly from claystone in these bedrock units. Some of the other fine-grained deposits with scattered clasts, such as the pebbly silty sand, may also be debris-flow deposits. In addition, large boulders (6 m or more in length) near the base of the Rocky Flats Alluvium, such as those that are about 0.9 km south of the map area, may have been transported by debris flows (Van Horn, 1976).

### Landslides

Landslides include a wide variety of mass movements produced by the downslope transport of surficial materials and bedrock by gravity. They are very common in the map area along the margins of the Rocky Flats surface. Landslide types that were recognized in the map area include: earth flows, earth slumps, debris flows, debris slumps, rock-block slides, and complex landslides (Varnes, 1978). Although briefly mentioned by Malde (1955), the extensive landslides in the map area were first recognized and mapped by Colton and others (1975) in their overview of Colorado landslides. During observation of aerial photographs and field mapping, landslides were identified by: (1) their hummocky topography, (2) deflection of stream channels by landslide toes, (3) scarps and depressions at their heads--the latter of which commonly contains springs and seeps--, and (4) intact masses of material downslope of their sources. Low-sun angle and occasional thin, discontinuous snow covers highlighted the subdued topography associated with many of the old landslide deposits. In addition, some of the colluvium (Qc) shown on this map locally consists of old landslide deposits the initial topography of which has been extensively modified by erosion so that they can not be identified with certainty. Generally, the landslide deposits in the map area are thin to moderately thick. The scarp heights of many of the young small landslides suggest that they have a thickness of about 3-10 m. However, some of the old, large landslides, such as the landslide near the southeastern corner of the map area, may be as much as 30 m thick.

Two main factors are likely to be responsible for the numerous landslides in the map area. They are: (1) saturation of bedrock and surficial deposits by springs and seeps, and (2) steep slopes underlain by the Arapahoe and Laramie Formations, which contain numerous bedding planes that can serve as slip planes, as well as abundant claystone that contains expansive clay. Landslides in the Denver area commonly occur on slopes steeper than 8° where fine-grained, weakly indurated, sedimentary rocks of low shear strength, such as the Arapahoe and Laramie Formations, are capped by lava flows or gravel such as the Rocky Flats Alluvium (Shroba, 1982).

Landslides in the map area range in age from the middle Pleistocene to the present. Landsliding probably began soon after streams in the eastern part of the map area eroded through the Rocky Flats Alluvium and exposed the underlying expansive claystone and weakly indurated siltstone and sandstone of the Arapahoe and Laramie Formations. Many of the landslides in the map area are thought to be young (Holocene). Fresh landslide scarps are present in all of the drainages of the map area and are most numerous in the Rock Creek drainage. Young landslide deposits are commonly bounded upslope by crescentic headwall scarps and downslope by lobate toes. Because of the lithologic characteristics of the Arapahoe and Laramie Formations, scarps formed in these formations or in surficial deposits derived from these formations are easily eroded. Readily recognizable scarps may be less than a few hundred years old. In fact, landslides at several localities have formed in artificial fill or displace other man-made features at the Rocky Flats Plant, indicating an age of 40 years or less. Small open fissures, less than 5 cm wide, that extend along slopes for several tens of meters in the northeastern part of the map area, indicate landsliding is an ongoing process in the Rocky Flats area.



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### CONVERSION FACTORS

| Multiply  | By      | To obtain                                       |
|---|---------|---|
| centimeters (cm)                                    | 0.3937  | inches (in)                                     |
| meters (m)  | 3.2808  | feet (ft)                                       |
| kilometers (km)                                     | 0.6214  | miles (mi)                                      |
| kilonewton per<br>square meter (kN/m <sup>2</sup> ) | 20.8333 | pounds per<br>square foot (lb/ft <sup>2</sup> ) |

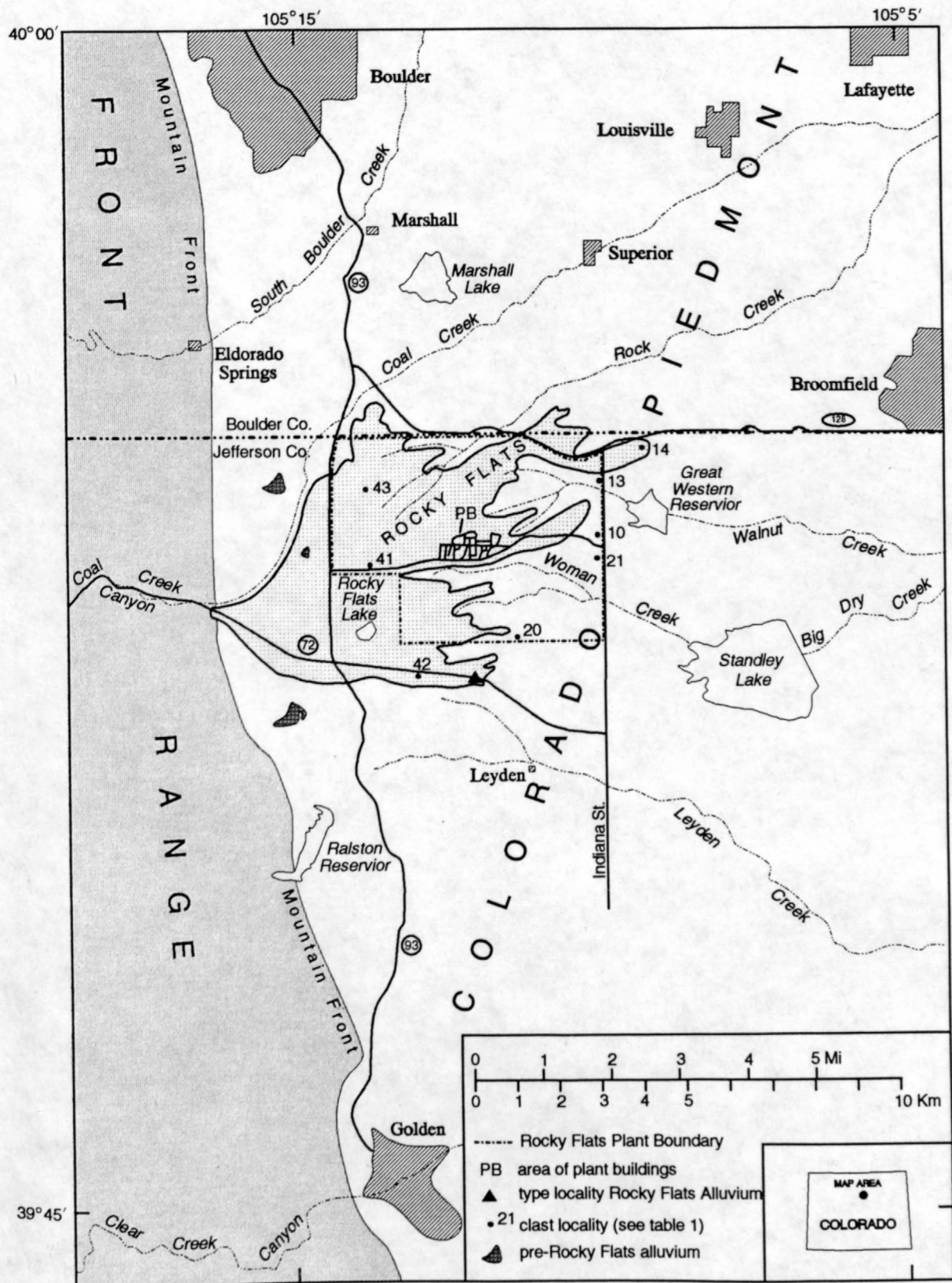


Figure 1. Generalized map of Rocky Flats and surrounding area.

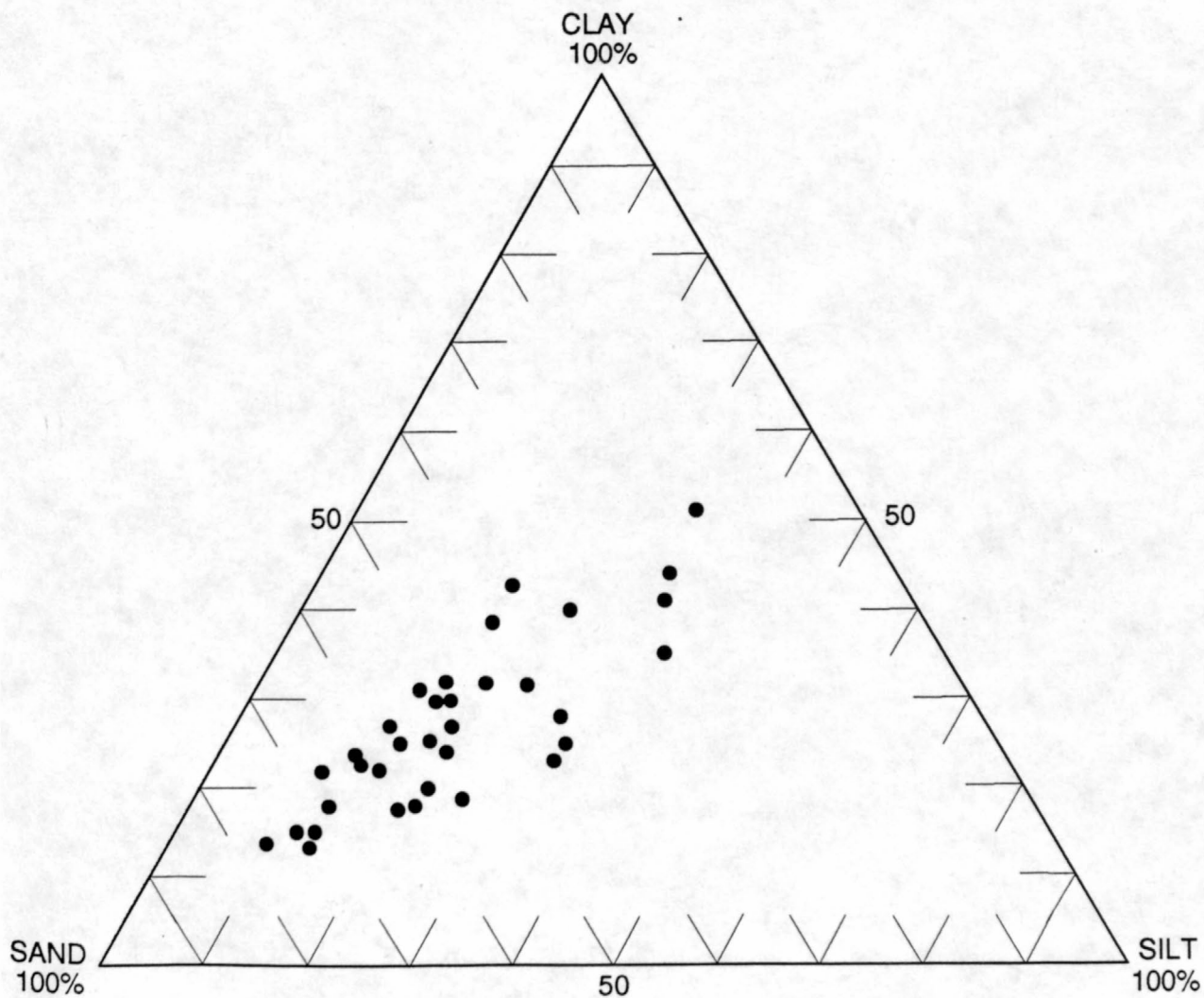


Figure 2 Percentage of sand, silt, and clay in the less than 2 mm-size fraction of some of the sandy and gravelly beds in the Rocky Flats Alluvium near the Rocky Flats Plant buildings (EG&G, 1991; Appendix D). Particle-size limits for sand are 2-0.05 mm, for silt 0.05-0.002 mm, and for clay less than 0.002 mm. All samples are from a depth of 1.5-12 m.



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