M I E R A S

Reconnaissance Report on Geologic Cond
OSMP Studies 4270
Study
Mieras, Barbara L

Reconnaissance Report on Geologic Conditions

Eldorado Mountain Management Area

City of Boulder Open Space/Real Estate

March 28, 1996

Barbara L. Mieras, Ph.D.
WPG #560

Contents

Introduction

The purposes of this reconnaissance on the Eldorado Mountain Management Area are 1) to summarize geologic conditions in the area and 2) to identify areas of particular geologic interest or concern. The Eldorado Mountain Management Area is administered by the City of Boulder Open Space/Real Estate Department. It lies along the southern edge of Boulder County and is bordered roughly by State Highway 93 on the east, State Highway 170 on the north, a line north through Eldorado Mountain on the west, and the Boulder County-Jefferson County line on the south, with the exceptions of a small block extending into northern Jefferson County and a small isolated block in the mountains northwest of Eldorado Mountain.

Field checks of the study area were made in a broad-brush way to catalogue the range of geologic conditions represented in the area. No attempt was made to address related topics that are covered in other studies such as those on wetlands or on soils. No systematic searches were undertaken to determine the extent or distribution of specific geologic features such as mineralization or dinosaur tracks.

Please refer to the accompanying Boulder area stratigraphic section (Figure 1) for general information on geologic units represented in the region and to the geologic sketch map of the study area (Figure 2) and schematic cross-section (Figure 3) for the distribution of geologic rock units across the Eldorado Mountain Management Area. Additional information is available in the references listed at the end of this report.

General Description: Geologic Overview

Stratigraphic Overview

The Eldorado Mountain Management Area lies in and along the foothills on the eastern flank of the Front Range of the Southern Rocky Mountains (Photo 1). The area includes rock units from about 1.7 billion to 65 million years old as well as unconsolidated surficial deposits laid down over the last 2 million years (Figure 1). Erosively truncated sedimentary rock layers are upturned against older, Precambrian rock units that are exposed in the mountain ranges (Figure 2). The age of rock units exposed at the ground surface generally decreases from west to east (Figure 3).

The oldest rock units in the area are the igneous and metamorphic rocks that underlie the foothills at the western margin of the management area. The eastern portion of the foothills, as well as the pediment and mesa areas, are underlain by younger sedimentary rock units. Still younger unconsolidated deposits, such as the thin gravelly alluvium that caps the mesa tops, represent more recent deposition. Loose piles of talus at the base of cliffs, stream bed and floodplain deposits along the creeks, eroded rubble along the sides of the mesas, and the development of soils reflect active, ongoing geologic processes.

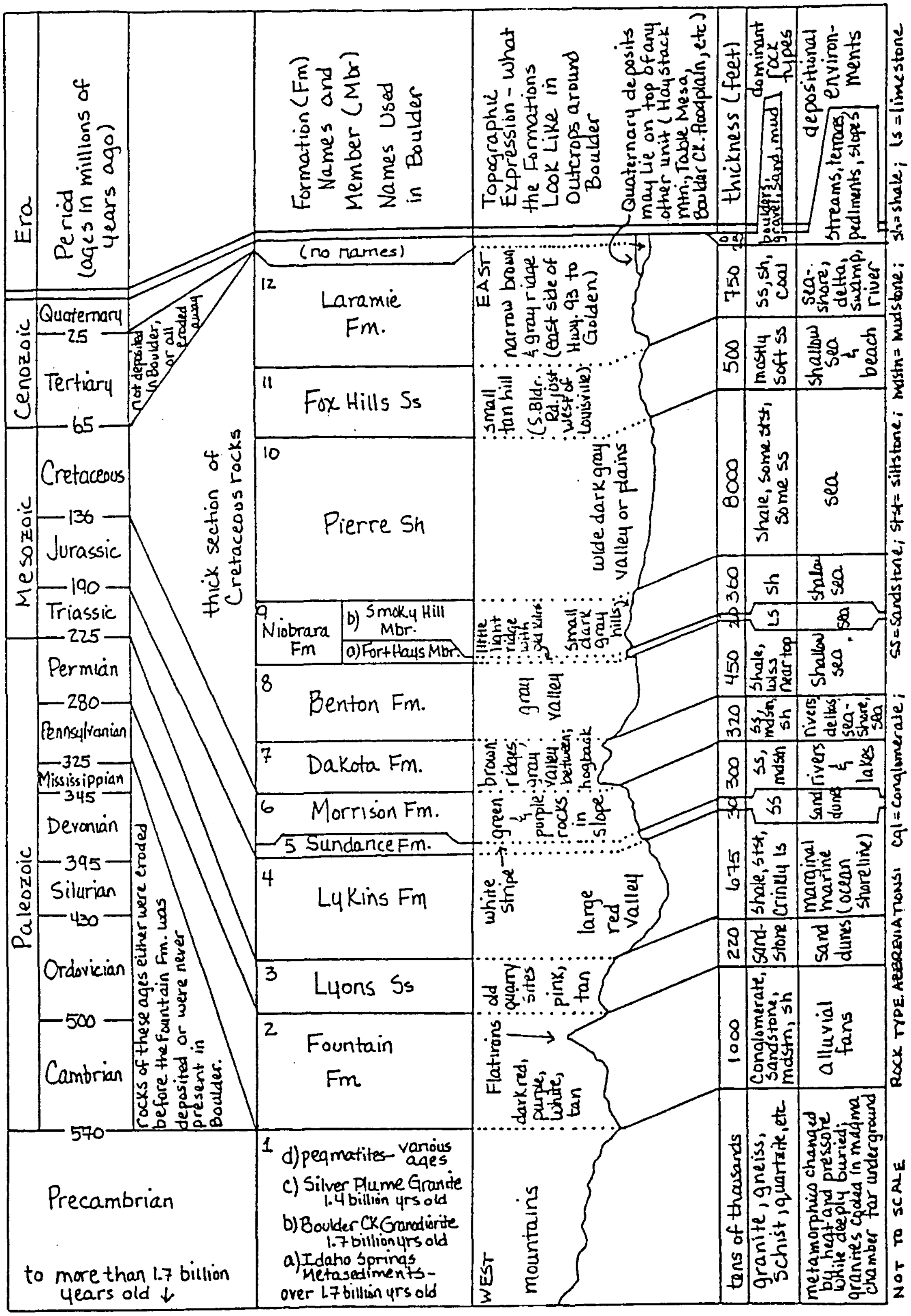


Figure 1: Summary of Boulder stratigraphy
(not to scale)

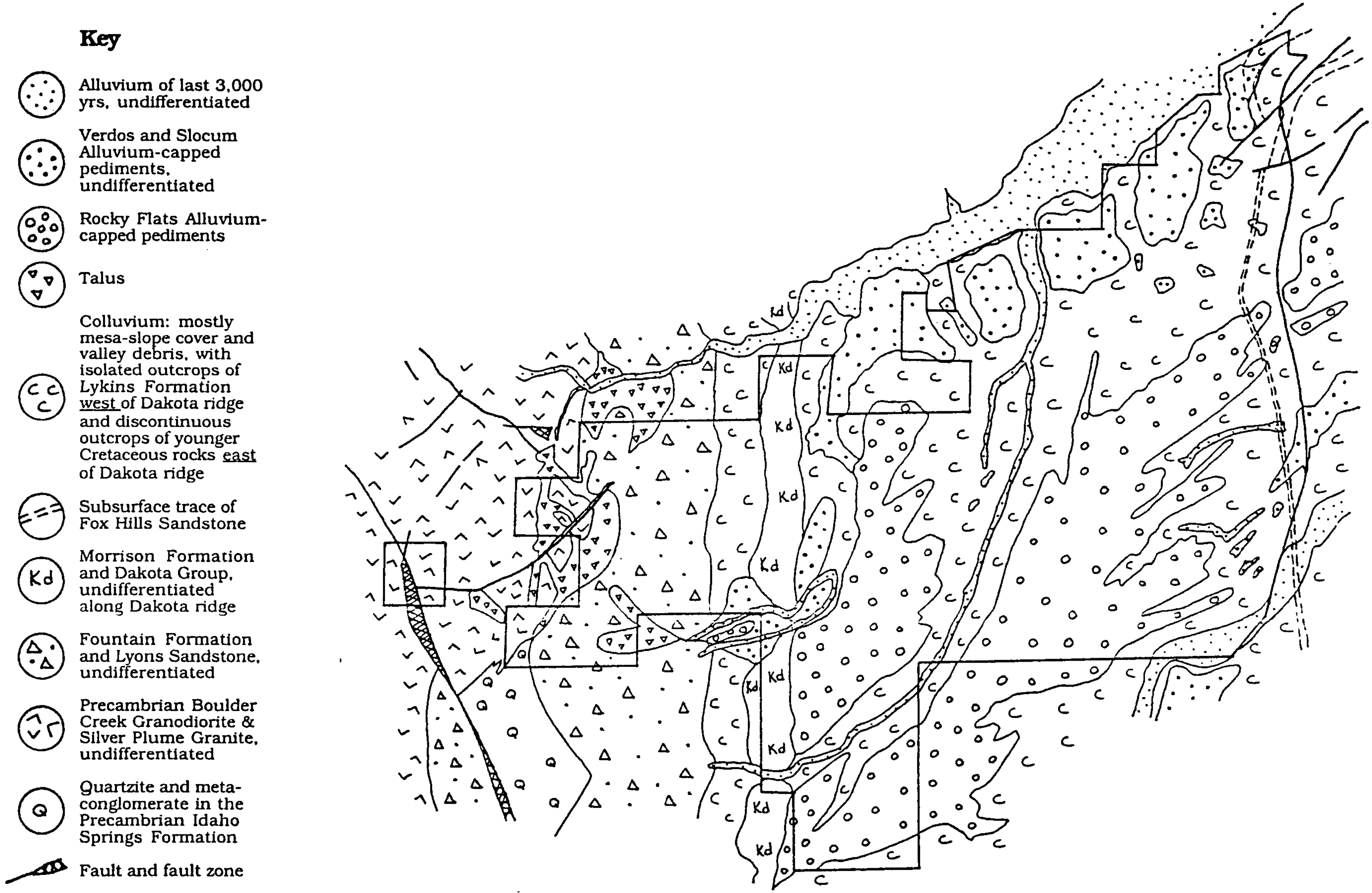


Figure 2: Sketch map of geology of Eldorado Mountain Management Area (within bold outline)
Geology summarized from Malde (1955), Spencer (1961), Scott and Cobban (1965), and Wells (1967).

Key

For names of rock units numbered 1 through 12, refer to "formation and member names" column in Figure 1.

Qa = Alluvium of last 3,000 years

Qc = Colluvium

Qt = Talus

Qv = Verdos Alluvium-capped pediment

Qrf = Rockу Flats Alluvium-capped pediment

QMC = Quartzite and metaconglomerate in the Precambrian Idaho Springs Formation

= Fault and fault zone

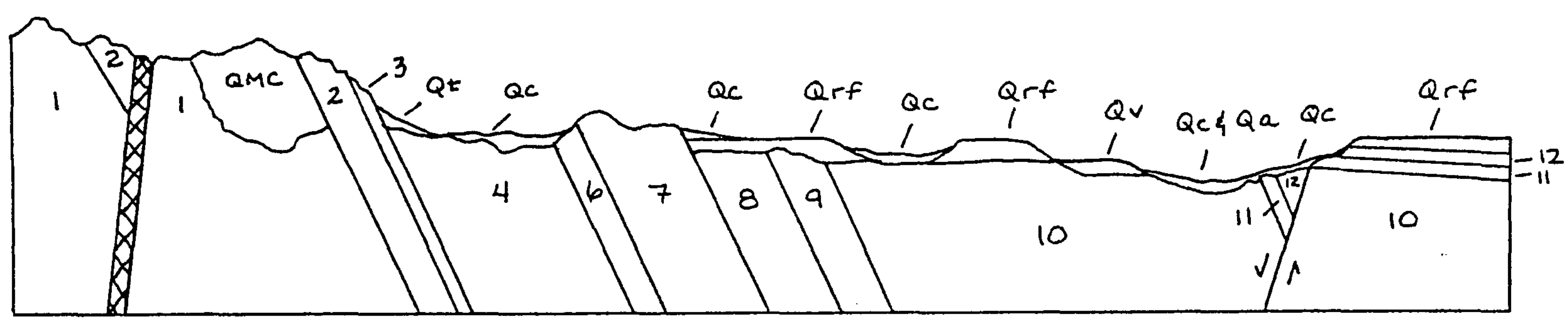


Figure 3: Schematic cross-section of Eldorado Mountain Management Area
(not to scale)

Photo 1: Looking west across Eldorado Mountain Management Area.

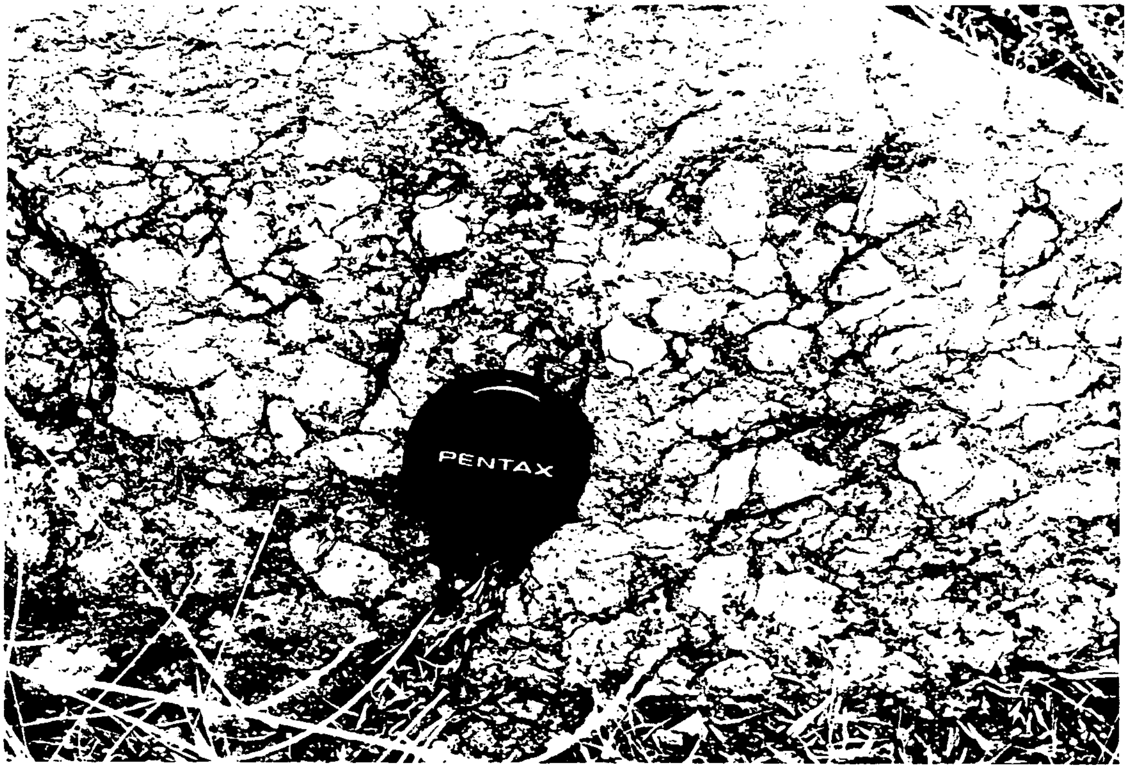


Photo 2: Metaconglomerate with quartzite cobbles, Precambrian Idaho Springs Formation, 1.7 billion years old.

Photo 3: Looking west across southern flank of Eldorado Mountain. Light-colored ridge in left background is Precambrian quartzite and metaconglomerate. Pinker ridges in front are Fountain Formation and Lyons Sandstone.

Photo 4: Red scars of Lykins Formation exposed in former quarry.

Photo 5: Morrison Formation in former quarry road. Angular blocks are rockfall from conglomeratic and sandstone units at the bottom of the Dakota Group which is exposed uphill above the Morrison Formation.

Precambrian Rocks: Among the Precambrian units on the Eldorado Mountain Management Area are the Idaho Springs Formation (1.7 bya), the Boulder Creek Granodiorite (1.7 bya), and the Silver Plume Granite (1.4 bya). Dikes and sills of Precambrian coarse-grained pegmatite and fine-grained aplite (1.0 bya) locally cut the older Precambrian rocks.

A unique unit within the Idaho Springs Formation contains metamorphic quartzites and metaconglomerates (Photo 2) that are exposed on the summit and southwest flank of Eldorado Mountain (Photo 3). The area from Eldorado Mountain south to Coal Creek is the only place where this unit is preserved. It records ancient episodes of mountain building, deformation, and erosion that are poorly documented elsewhere in the Precambrian rock record.

Paleozoic Rocks: The oldest sedimentary rocks preserved in the area are in the conglomeratic Fountain Formation. An unconformity representing as much as 1.4 billion years of "missing time" separates the 300 million-year-old Fountain Formation from the underlying Precambrian rocks. The Fountain Formation was deposited in alluvial fans built on the eastern flank of the ancient Ancestral Rocky Mountains during arid climatic conditions.

Arid conditions persisted about 250 million years ago while the Lyons Sandstone was being deposited. North of Boulder, where the Lyons Sandstone was deposited mostly in windblown sand dunes, the rock layers part evenly along flat bedding planes that were left during growth of the dunes. But in the Eldorado Mountain Management Area, more of the Lyons Sandstone was deposited by rivers, and the rock does not break as evenly, nor is it as useful for building stone as its counterpart to the north.

Mesozoic Rocks: The Lykins Formation contains mudstones, siltstones, sandstones, and limestones that were deposited along the shoreline of a shallow sea about 200 million years ago. It is locally quarried for clay and aggregate (Photo 4).

The Morrison Formation (Photo 5) records deposition in and along lakes and slow-moving streams that lay amid the ancient lowlands left after the erosion of the Ancestral Rockies. A wetter climate contributed to increased food supplies for land-dwelling animals, including dinosaurs. Dinosaur bones are commonly found in the Morrison Formation throughout the region.

The rocks of the Dakota Group, Benton Formation, Niobrara Formation, Pierre Shale, Fox Hills Sandstone, and Laramie Formation record the advance and retreat of the Cretaceous Sea that covered the area from about 100 million to almost 65 million years ago. The seaway lay in a north-south band that spanned the entire length of the western interior region of today's North American continent.

The Dakota Group, the Fox Hills Sandstone, and the Laramie Formation were deposited along the shoreline of the sea. The Dakota Group was deposited as the sea entered the area, and the Fox Hills Sandstone and the Laramie Formation were deposited as the sea left the area. The Fox Hills Sandstone was deposited primarily in beaches and closely related environments. The Dakota Group and Laramie Formation both contain dinosaur tracks, plant fossils, and other evidence that show they were deposited at least partly on low-lying land (Photo 6). A wave-rippled bed in the younger part of the Dakota Group was deposited on tidal flats and now forms the distinctive "ripple rock" on the Lindsay property in the Eldorado Mountain Management Area (Photo 7). Refractory clays were quarried from the Dakota Group on the Eldorado Mountain Management Area, and both the Dakota Group and the Laramie Formation have been quarried for these clays in nearby areas. Coal beds in the Laramie Formation have been extensively mined east of the Eldorado Mountain Management Area. Surficial mineralization along fractures and bedding planes is locally prominent in Dakota Group sandstones and in concretions of both the Morrison Formation and Dakota Group.

The Benton Formation, Niobrara Formation, and Pierre Shale were deposited mainly within the sea itself. They consist primarily of soft shales and mudstones with some relatively non-resistant sandstones. They also contain bentonite beds formed from airborne volcanic ash that settled to the bottom of the sea. The bentonites contain swelling clays that can cause structural damage. The Niobrara Formation also contains limestone and limey shales that are quarried in the Lyons area. The Pierre Shale is quarried for lightweight aggregate along Highway 93 southeast of the Eldorado Mountain Management Area (Photo 8).

Cenozoic Deposits: No rocks of lastest Cretaceous or Tertiary age are preserved in the Eldorado Mountain Management Area, although some mappers have included small areas of the Arapahoe, Denver, or Dawson Formations in nearby areas to the southeast. A few small Tertiary igneous intrusions cut the Precambrian rocks in the mountains west of the management area.

There are, however, significant unconsolidated deposits from the last 2 million years representing alluvial deposition by streams and in alluvial fans. Dissected, alluvium-capped pediments form a series of prominent mesas at several elevations (Photo 9). The pre-Rocky Flats Alluvium caps isolated remnants of higher mesas just to the south of the Eldorado Mountain Managment Area. Within the management area itself, the <u>Rocky Flats Alluvium</u> (2 mya - 1 mya) caps the highest mesas. Somewhat lower mesas are capped by the <u>Verdos Alluvium</u> (600 kya), and still lower mesas are capped by the <u>Slocum Alluvium</u> (260 kya - 150 kya). Nearby, outside the management area, still lower surfaces are capped by the Louviers Alluvium (140 kya) & the Broadway Alluvium (30 kya). Still lower, along modern streams, are alluvial surfaces that include <u>pre-Piney Creek</u>, <u>Piney Creek</u> (2800 ya), <u>post-Piney Creek</u> alluvium (1500 ya), and modern alluvial deposits. The Louviers, Broadway, and Piney Creek alluviums contain relatively unweathered clasts and are quarried for sand and gravel in the Boulder area.

Also significant in the Eldorado Mountain Management Area is the <u>colluvium</u> formed from downslope movement of eroded rock debris in valleys, on the slopes of mesas, and in the talus piles at the base of cliffs (Photos 10 and 11).

In the Boulder area, soils developed on deposits of these ages are locally collapsible when they are saturated, especially where they have high silt or clay content. Collapse on the order of several feet may lead to structural damage.

Topographic Overview

The Eldorado Mountain Management Area lies along the foothills of the eastern flank of the Front Range of the Southern Rocky Mountains. It is situated between two northeast-trending drainages, South Boulder Creek to the north and Coal Creek to the south. Ground surface elevations increase in a general way from east to west and from north to south. Area elevations range from just over 5500 feet in the northeast corner of the area to 8354 feet on the summit of Eldorado Mountain.

The bedrock fabric underlying the area trends generally north-south. It is established by upturned layers of sedimentary rock lying against the older igneous and metamorphic core of the mountains (Figures 2 and 3). On the Eldorado Mountain Management Area, two primary north-south ridges of resistant sedimentary rock parallel the mountain front (Photo 12). The western ridge is composed of the Fountain Formation and Lyons Sandstone. Talus slopes are common in canyons cut in the Precambrian rocks and along the Fountain-Lyons ridge. The eastern ridge is supported by the lower conglomeratic and sandstone units of the Dakota Group (Photo 13). Between the Fountain-Lyons and the Dakota ridges lies a colluvium-filled valley with isolated outcrops of the Lykins Formation and Morrison Formation. Drainages within the management area cut the Dakota ridge more or less perpendicular to its trend, then turn northward toward the South Boulder Creek drainage.

In areas east of the Eldorado Mountain Management Area, particularly around Marshall Mesa, ridges are also produced by the Fox Hills Sandstone and the Laramie Formation, especially where sandstones in these formations are uplifted along faults, but these units are largely covered by surficial deposits in the management area (Photo 14).

East of the Dakota ridge in the Eldorado Mountain Management Area, the upturned sedimentary rock layers that parallel the foothills are less resistant. They have been eroded to relatively planar surfaces that slope gently toward the plains. These pediment surfaces are mostly covered with a thin veneer of erosional rubble topped with thin soils (Photos 15 and 16). Some of the rubble is colluvium moved primarily by gravity, but the majority of it is alluvium moved mainly by streams. The alluvium on the pediments is oldest on the highest surfaces and youngest on the lowest surfaces, reflecting the continued downward cutting of stream drainages in the area. Some of the alluvial surfaces were deposited during the Pleistocene glaciations. Others were deposited more recently. The trend of the pediment surfaces is generally to the northeast in accordance with modern stream drainages. The pediment surfaces give the area east of the Dakota ridge a dominant southwest-northeast fabric that is different from the north-south fabric to the west of the ridge (Figure 2).

Seeps, springs, small wetland areas, and ephemeral ponds are scattered across the area. Faults and fracture zones, upturned aquifer beds, alternating layers of aquifer and aquitard, and regional west-to-east elevation gradient contribute to these. Human construction of berms and quarrying

Photo 10 : Slope covered with thin veneer of rubbly colluvium. Bedrock in Pierre Shale exposed in small slump. Diagonal line through bedrock is a bed of small concretions. These commonly contain fossils such as clams or ammonites.

Photo 11: Dipping beds of Pierre Shale in Doudy Draw, with thin cover of colluvial rubble.

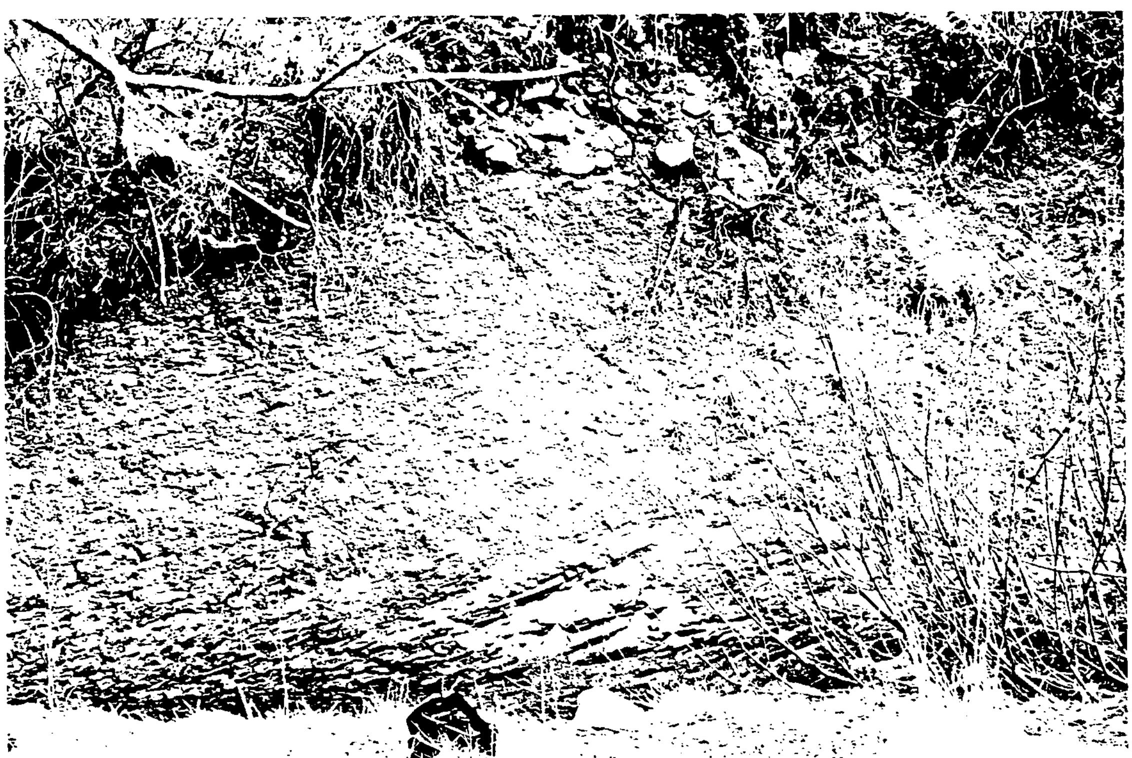


Photo 8: Dark gray exposures of Pierre Shale exposed in aggregate quarry along Highway 93 just southeast of Eldorado Mountain Management Area.

Photo 9: View northwest across northern end of Eldorado Mountain Management Area showing cattle grazing on flat-topped pediment surfaces that are capped with alluvium.

Photo 6: Cast of dinosaur track exposed on bottom of sandstone bed in the upper part of the Dakota Group.

Photo 7: Bed of "ripple rock" exposed by quarrying where fire clay was stripped from its surface.

Photo 12: Looking north up colluvium-filled valley that was cut in nonresistant Lykins Formation. Valley lies between western ridge of Fountain Formation and Lyons Sandstone and eastern ridge of conglomerate and sandstone in the lower Dakota Group.

Photo 13: Atypically thick Plainview Sandstone in the lower part of the Dakota Group, exposed at road cut on former quarry road. The unit was named for exposures at Plainview, just southwest of the Eldorado Mountain Management Area.

Photo 14: Movement along northeast-trending faults has produced ridges of Fox Hills Sandstone and Laramie Formation in the Marshall Mesa area just east of the Eldorado Mountain Management Area.

Photo 15: Upturned, erosionally truncated beds of Pierre Shale exposed along ditch system and covered by a thin veneer of colluvium and soil.

Photo 16: Gentle colluvium-covered slopes on mesa-top capped with Rocky Flats Alluvium, southern end of Eldorado Mountain Management Area.

pits, as well as leakage from diversion pipes and canal systems, has also contributed water to some wetland areas (Photos 17 and 18).

Units with alternating layers of more-resistant and less-resistant rock (including parts of the Fountain Formation, the Morrison Formation, and parts of the Dakota Group) and units dominated by soft shaley rock (including most of the Lykins Formation, the middle Dakota Group, the Benton Formation, Pierre Shale, and parts of the Laramie Formation), are prone to slumps and landslides. This effect is accentuated where the rock layers are tilted and is especially prevalent where they are exposed in a steepened slope, regardless of whether the slope is natural or was artificially produced by activities such as road-building or trail-cutting. The effect is mitigated, although not completely compensated, where the rocks are protected by an overlying veneer of alluvium or colluvium.

Structural Overview

The dominant north-south fabric established by the upturned sedimentary rock layers underlying most of the Eldorado Mountain Management Area is overlain by northeast-trending drainage systems and alluvium-covered pediments. This northeast fabric is replicated in northeast-trending faults that enter the northeast corner of the Eldorado Mountain Management Area. Offsets on these faults are seen in the Pierre Shale, Fox Hills Sandstone, and Laramie Formation in Marshall Mesa and adjacent areas. The faults probably are genetically linked to the Idaho Springs-Ralston Creek Shear Zone that trends northeastward toward the southern margin of the management area. Regional structural trends reflected in the shear zones probably helped to localize the development and preservation of Cretaceous coal swamp deposits.

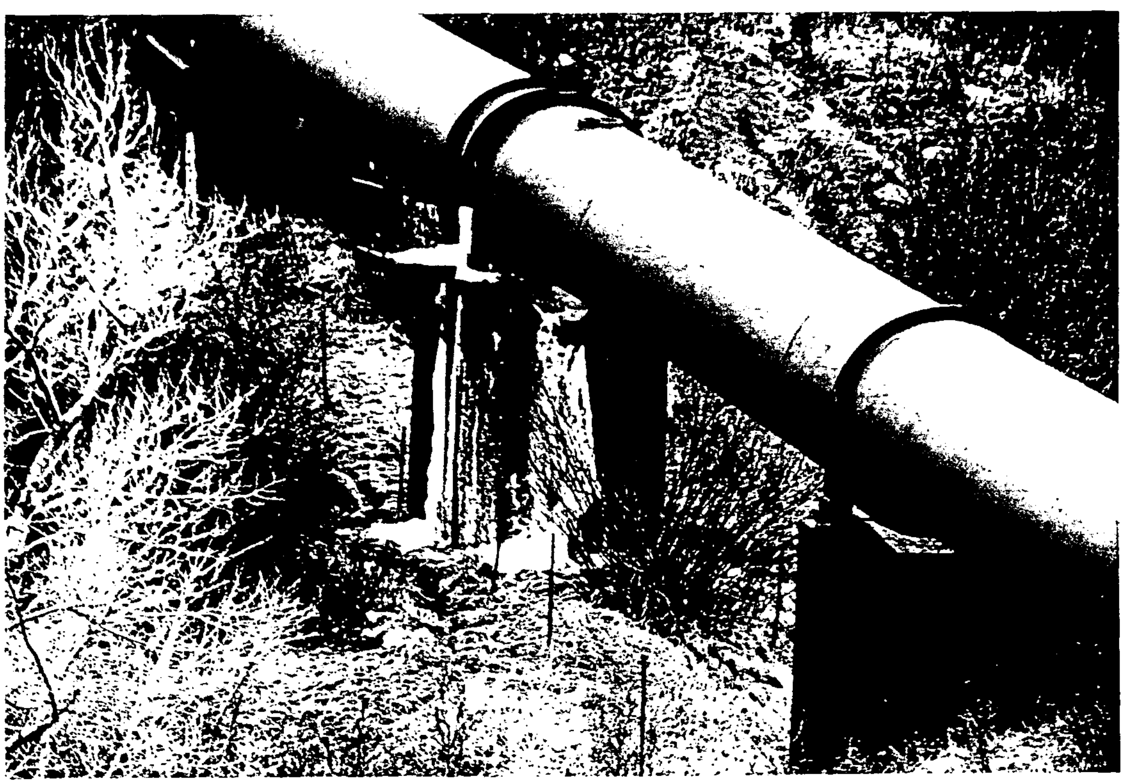
Antithetic to this trend are major sets of northwest-trending faults in the mountains at the western margin of the management area. Just to the north, the Hoosier Fault and its breccia zones run northwest up Shadow Canyon between South Boulder Mountain and Bear Peak (Photo 19). The Livingston Fault and its breccia zones run directly through the Schneider property at the western extremity of the Eldorado Mountain Management Area. Tertiary mineralization in Precambrian rocks in the Colorado Mineral Belt is particularly associated with northeast-trending fault systems, but mineralization also occurs along the northwest-trending faults, especially where they intersect northeast-trending faults, as is the case on the Schneider property. Interesting mineralization may occur in this area.

Overview of Interaction of Geology, Flora, and Fauna

Geologic conditions exert strong influence on vegetation types, diversity, and abundance by controlling factors such as topography, relation between rock type and soil type and rate of soil formation, availability of specific nutrients, potential of rock units for holding and moving groundwater and surface water, opportunities for rootholds, and opportunities for shelter from the sun, temperature fluctuations, and weather conditions. Floral distributions in turn strongly affect faunal distributions. Geologic conditions also directly affect faunal distributions by providing enhanced or depleted opportunities for critical factors such as

Photo 17: Small wetland, enhanced by artificial berm, on pediment surface covered with Rocky Flats Alluvium, southern end of Eldorado Mountain Management Area.

Photo 18: Leaking diversion pipe contributes water to area of natural springs and seeps in Doudy Draw at boundary between Boulder and Jefferson counties.



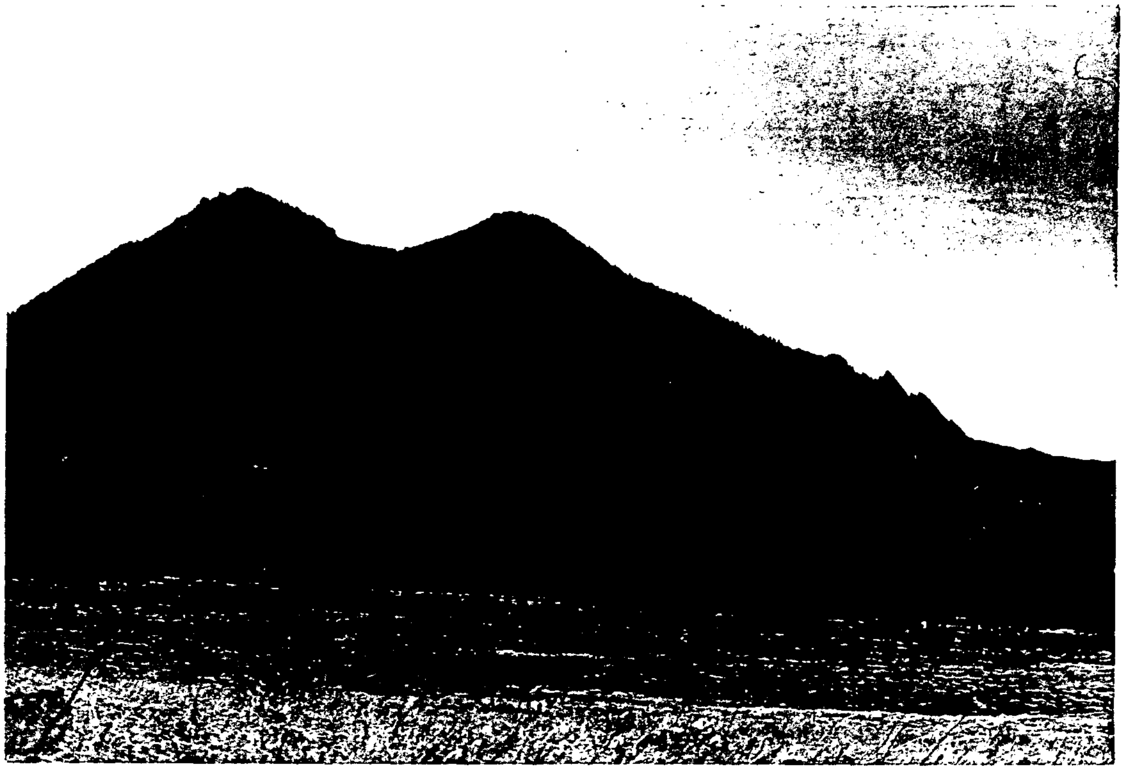


Photo 19: Looking north into Shadow Canyon along Hoosier Fault separating South Boulder Peak from Bear Peak.

Photo 20: Variety of rock units underlying Eldorado Mountain Management Area leads to variety of habitat for plants and animals.

shelter and mobility and by strongly controlling topographic expression and the availability of water.

The variety of rock types, structural settings, and topographic expressions in the Eldorado Mountain Management Area combine to produce diverse habitat opportunities for flora and fauna (Photo 20). Deeply cut canyons and rockfall areas on the western margin of the property offer enhanced sheltering and nesting opportunities for land, tree, and cliff dwellers. Dense tree and brush growth and considerable local relief on colluvium between the Fountain-Lyons and Dakota ridges offers similar advantages. Springs and seeps throughout the area augment the habitat.

Acidic bedrock in the mountainous western margin of the Eldorado Mountain Management Area supports Ponderosa pine growth and, at higher elevations, Douglas fir forests. Acidic rubble in alluvial gravels on mesas, especially in the Rocky Flats Alluvium, also supports Ponderosa pine growth as well as dry grasslands (Photo 21). Tree growth in mountain and pediment areas is enhanced where fractured bedrock, shallow aquifers, and unconsolidated surface material transmit groundwater. The Fox Hills Sandstone and Laramie Formation are predominantly buried beneath surficial rubble in the management area, but where aquiferous sandstones in these formations crop out east of the management area, they also support tree growth.

Highly resistant sandstone layers such as those in the Lyons Sandstone and basal Dakota Group commonly form lichen-covered rock outcrops that support few trees.

Nonresistant colluvium and nonresistant bedrock exposures on mesa slopes and in the north-south valley between the Fountain-Lyons and Dakota ridges support herbaceous growth and grasslands (Photo 22). The flanks of drainages and hillsides with seeps also support shrub growth. Trees also grow near some seeps and springs.

Issues Identification

Identification of geologic hazards or concerns and identification of geologic resources help inform issues of access and use and in some cases suggest the need for further study.

Identifying Geologic Hazards and Concerns

In the Eldorado Mountain Management Area, potentially hazardous or disruptive geologic conditions can be linked to:

- inherent stratigraphic properties of the rock units (e.g., slump-prone)
- topography (e.g., rockfall from cliff-faces, gravity-induced slides)
- potential for seismicity
- surface water and groundwater concerns
- natural radioactivity

Examples of these include:

Photo 21: Pediments with alluviual veneers typically support dry grasslands and Ponderosa Pine forests.

Photo 22: Below treed alluvium-capped mesas, colluvium-covered slopes typically support grasslands, while drainages and slopes with seeps support greater shrub growth, locally with trees.

- **Highly erodible nonresistant rock units** are easily damaged by a variety of impacts from runoff to animal trails to foot traffic (Photo 23); eroding these units can in turn cause damage to the structures they support and to the surrounding landscape. Some of these units, including the Pierre Shale, also contain unstable **swelling clays** that themselves can cause damage to trails and structures.

- **Mass movement: rockfall, slumps, landslides, debris flows, downslope creep**, and other forms of mass movement of rock and unconsolidated material are natural events that happen episodically under conditions favorable to their occurrence. Cliff-faces, zones of fractured bedrock, steep slopes, piles of rock rubble or other unconsolidated material on slopes, and tilted rocks layers, especially those with alternating layers of resistant and nonresistant rock, are consistent with episodic mass movement. The probability of occurrence is higher in areas with active seeps or high water tables. It is also heightened wherever rock cohesiveness and/or natural topographic slopes have been altered by activities such as quarrying, road building, or trail building.

  The Fountain Formation, Lykins Formation, Morrison Formation, Dakota Group, Benton Formation, Pierre Shale, and Laramie Formation each contain nonresistant **slump- and slide-prone** units. The Lykins Formation, Morrison Formation, Benton Formation, Pierre Shale, and Laramie Formation tend to lie in valleys and lower slopes in the Boulder area, so they have been less involved in large mass movement events, although small slumps and downslope creep are common in these units where they underlie slopes (Photo 24). The Fountain Formation and Dakota Group are prone to larger mass movement events because they tend to be situated on ridgetops. Debris flow deposits with van-sized boulders of Fountain Formation reach as much as two miles out from the foothills near the study area. Large blocks of land underlain by rocks of the Dakota Group have slid downslope along the foothills at multiple locations in Boulder County.

- **Quarried areas** can combine many of the concerns related to mass movement (Photo 25). Loosened rock slabs, oversteepened and unstable slopes and rock piles, standing or flowing surface water, ponded subsurface water, loose unconsolidated fill, little vegetative cover to slow runoff, and quarry positions in high places adjacent to ravines contribute to the possibility of major mass movement downslope.

- **Seismic events** increase the risk of mass movement. Considerable rockfall from cliffs, especially along fracture zones, can occur during moderate earthquakes. Rockfall, with or without a seismic trigger, may carry a considerable distance from cliff-faces. Seismic events can also rupture pipelines and canals or trigger landslides and slumps that can cause similar damage.

  Small and moderate earthquakes have been reported in the immediate area since the time of Euro-settlement of the Boulder Valley. In addition, offset alluvium indicates activity in the last 260,000 years on the Valmont Fault to the northeast. Similar evidence suggests that

Photo 23: Deer trails eroded into nonresistant Pierre Shale. These rock units underlie much of the area east of the Dakota ridge. Where they are exposed or covered only with thin colluvium or alluvium, they erode readily.

Photo 24: Slow downhill creep and slumping of surficial material is common on colluvium-covered slopes.

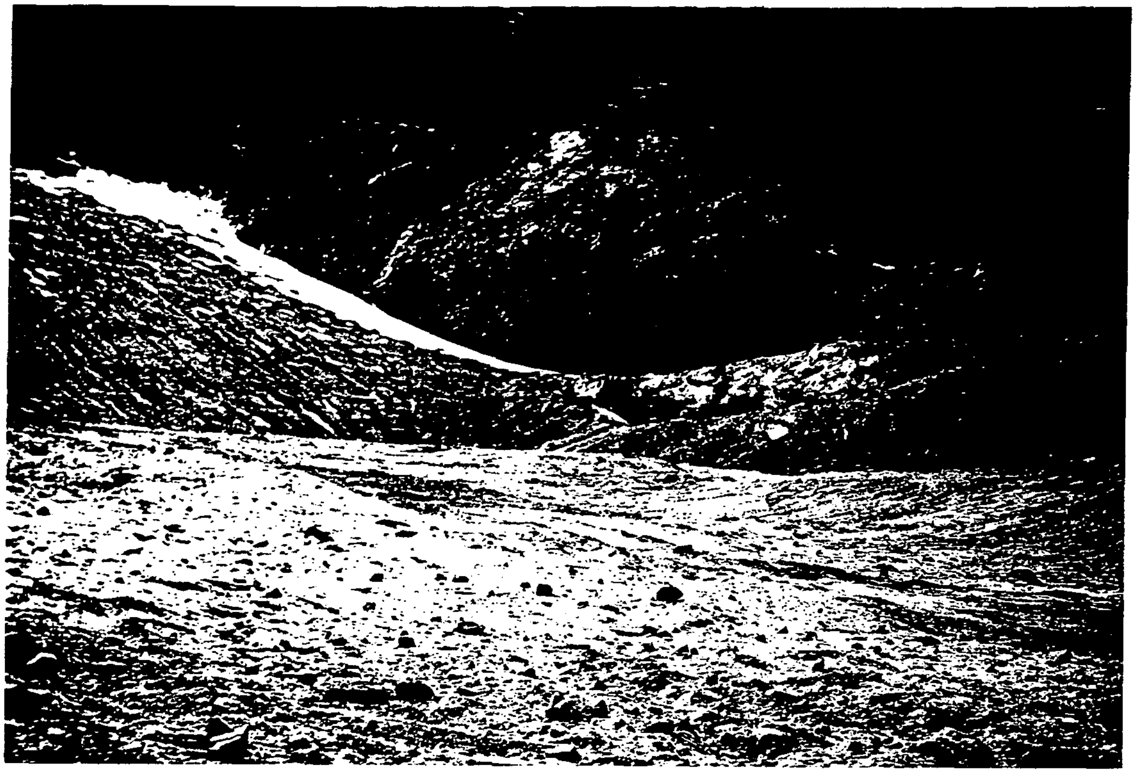


Photo 25: Looking west across Lykins Formation exposed in former quarry showing rockfall above quarry, steep quarry walls, and small wash-pattern developing across quarry fill material.

Photo 26: Cobbles transported by runoff from downpour and deposited along roadside.

major faults to the south and east are still active, although there have been no recent major earthquakes along these faults.

- **High relief and rugged topography** present a natural hazard in the form of abundant places to climb, fall, and get lost. Areas with extensively fractured rock, loose rock, or unstable blocks of rock present special hazards to climbers and to hikers below.

- **Underground dissolution** can lead to cavern development and collapse in limestones units like those in Lykins Formation. The possibility of major disruption is small in relatively thin limestones like those in the Lykins Formation, but the presence of springs issuing from limestones in the Lykins Formation in the area indicates that groundwater flow and dissolution of the limestones do occur.

- **Collapsible soils** in unconsolidated surficial deposits may compact when saturated and can cause trail damage and structural damage.

- **Subsidence related to coal-seam subsurface burning,** as well as subsidence related to subsurface coal mining, occurs in the Boulder region but primarily in intensely mined areas east of the Eldorado Mountain Management Area.

- **Surface and subsurface water** concerns include flashflooding and flooding on streams, ditches and canal systems and the possibility of existing and potential pollution affecting groundwater and surface waters in streams, springs, seeps, and wetlands.

  Flashflood damage is possible along creeks, ditches, and canals, especially where water flow is laterally confined by steep rock walls, but escape routes upslope from the path of potential flashfloods are generally available across the area. Flashflooding could be triggered by intense storms updrainage or by pipeline or canal ruptures. More generalized flooding is expected when weather and/or seasonal conditions result in exceptionally high runoff; even runoff from normal summer downpours can transport cobble-sized material (Photo 26). Exceptionally high discharge levels could damage bridges and trails.

- **Natural radioactivity** is high in specific rock units and their associated waters, particularly within Precambrian pegmatites and certain intrusions related to Tertiary mineralization of Precambrian rocks in the mountains. It is extremely unlikely that natural radioactivity would present a hazard to recreational users of the Eldorado Mountain Management Area.

Identifying Geologic Resources

A major component of the beauty and character of the Eldorado Mountain Management Area is its geological diversity. The area offers a range of geologic attractions on a variety of scales from mountain-size to microscopic. Large-scale features such as the mountains and the mesas help define the overall character of the area. But once within the area, many of the most eye-catching geologic features, such as fossils, mineral specimens, and pieces of ripple rock, are pocket-sized or can be made pocket-sized very quickly. Each of these small geologic resources is irreplaceable - when it is lost to the area, nature does not produce another to take its place. Although each of these geologic features is valuable, some particularly need to be considered for preservation or protection. These include:

- Unique or exemplary geologic features
- Fragile or unstable geologic features
- Geologic features that are critical to the support of particular ecosystems

Examples of features that fit these criteria in the Eldorado Mountain Management Area are:

- **Dinosaur tracks**, preserved as casts at the bottom of beds and as imprints on upper bedding surfaces. Dinosaur tracks already have been removed by "collectors" at many localities in the Boulder area. In addition to being attractive collectibles, dinosaur prints in the Eldorado Mountain Management Area are being destroyed by natural weathering processes (Photos 27 and 28).

- **"Ripple rock"** that preserves excellent examples of long-crested oscillation ripples.

- Other attractive **sedimentary features** such as delicate round-topped "mini ripples", mud crack clasts, fossilized imprints of wood, fossilized root marks, fossilized bone fragments, unusual mineralized concretions, and packed-pebble conglomerates that all occur in rocks of the Dakota Group in the Eldorado Mountain Management Area. Equally interesting sedimentary features certainly occur in other rock units that were not examined, and among these may be features such as reptile and amphibian tracks.

- **Invertebrate fossils** such as ammonites, clams, oysters, and stromatolites that are found in rocks deposited in seas and along shorelines. Several rock units of different ages are known to be fossiliferous nearby. There are a number of U.S. Geological Survey collection sites in Cretaceous rocks within the management area itself.

- **Plant fossils, petrified wood, and coal** are found in the Laramie Formation in the immediate area, but the Laramie Formation within the managment area boundaries is mostly buried below surficial alluvial deposits.

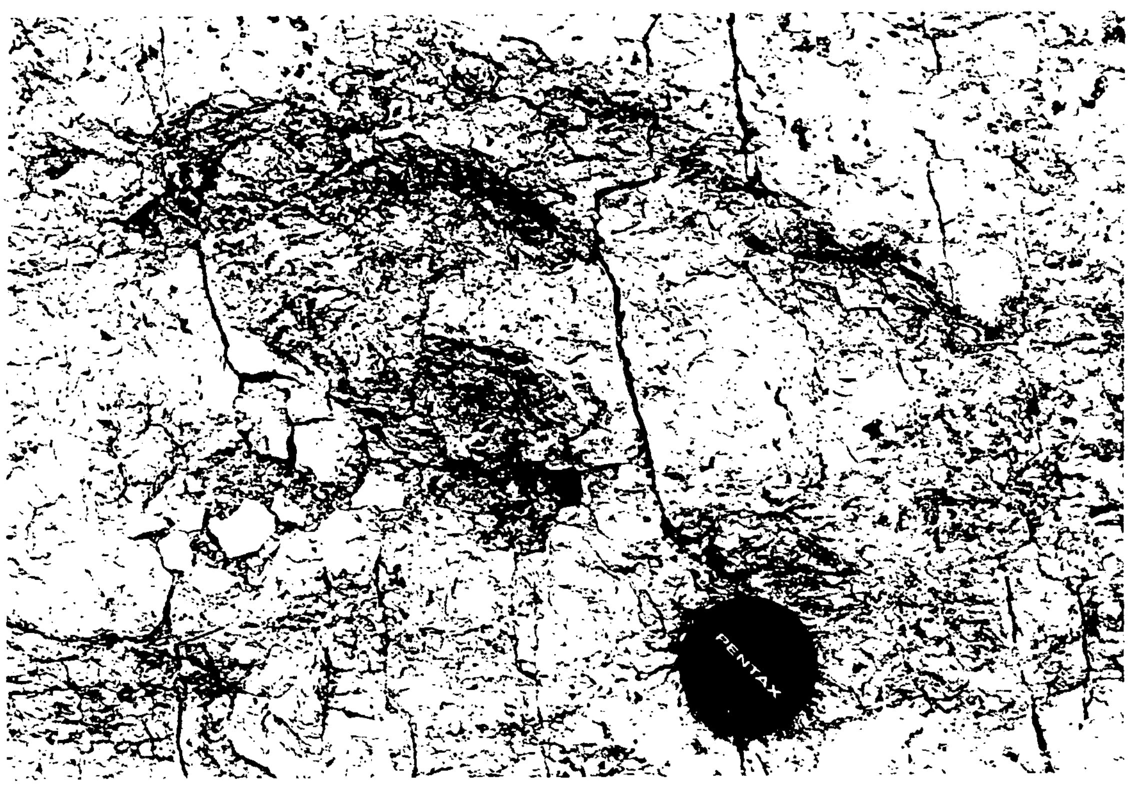
- **Bison horns and bones** may be present in unconsolidated surficial material on the high mesas and in associated drainages.

- **Attractive minerals and possibly ore-bearing rock** may occur in the Precambrian rocks on the western margin of the management area, especially in highly fractured zones.

- **Wetlands**, including ponds, springs, seeps, and associated drainages are controlled by geologic conditions.

Photo 27: Dinosaur tracks in upper Dakota Group exposed along diversion canal. Tracks are faint pits in light colored lobe of rock in center of picture.

Photo 28: Close view of one of the dinosaur tracks shown in previous photo. Lower left half of track (as viewed) is rapidly being destroyed by natural erosion processes.



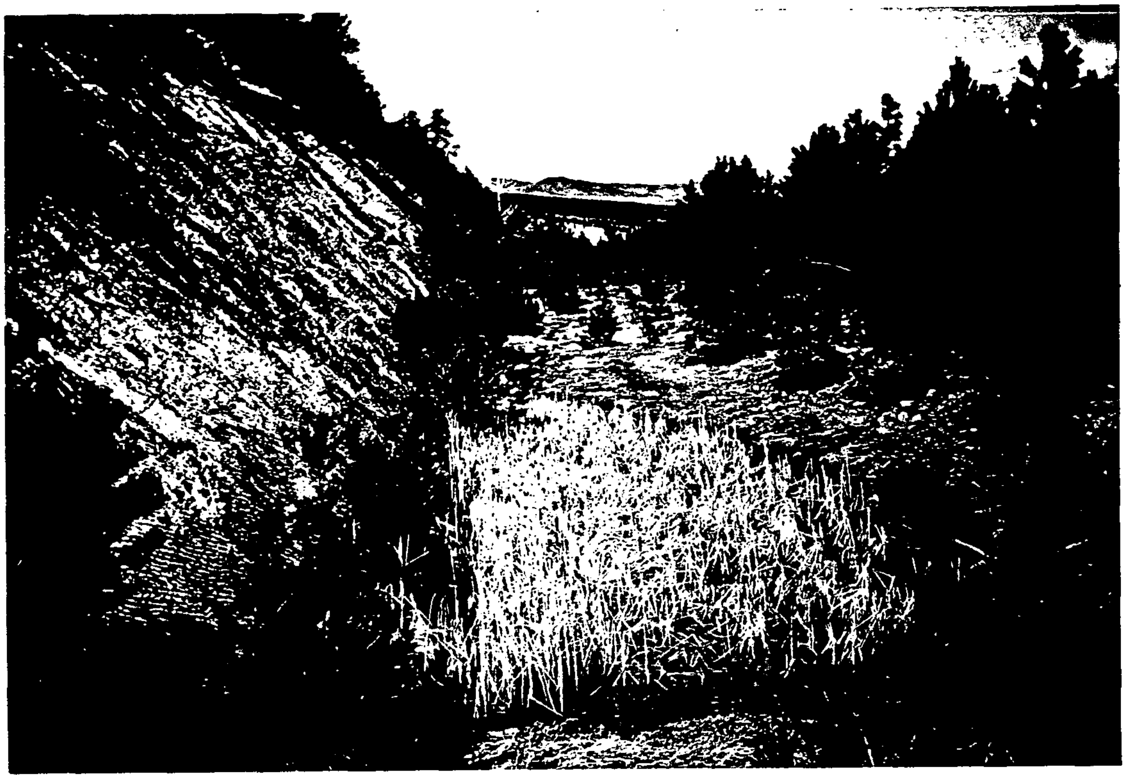


Photo 29: Small wetland along contact between "ripple rock" sandstone (aquifer) and fire clay (aquiclude) in upper Dakota Group.

Photo 30: Creek in area of springs and seeps, Doudy Draw near boundary of Boulder and Jefferson counties. Berm built downstream to retain water. Leakage from diversion pipe upstream adds to water supply.

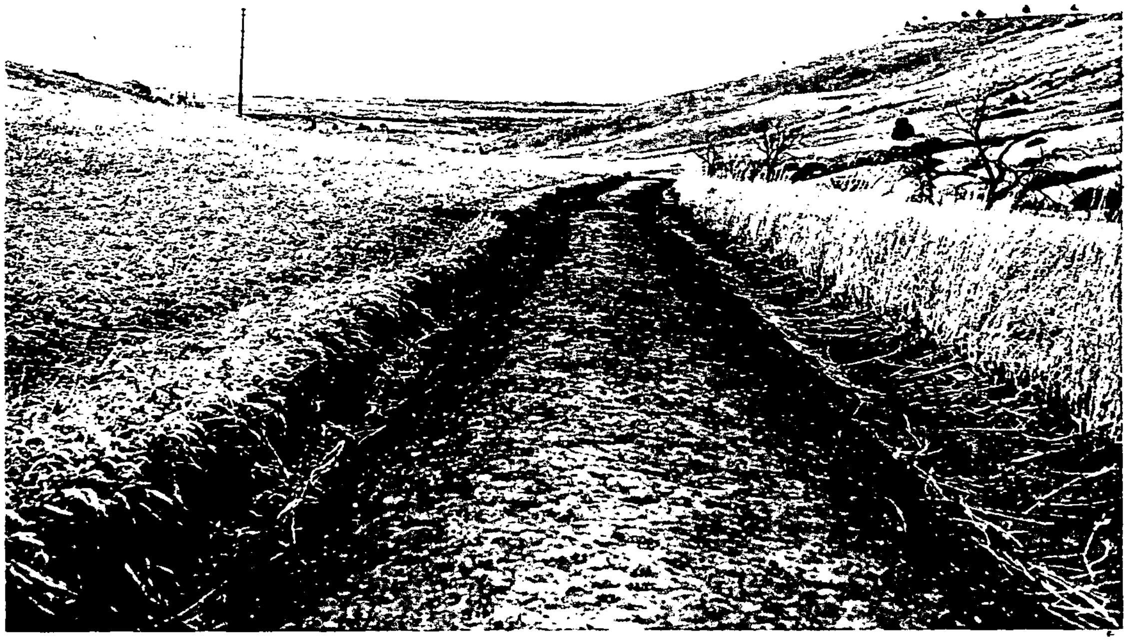
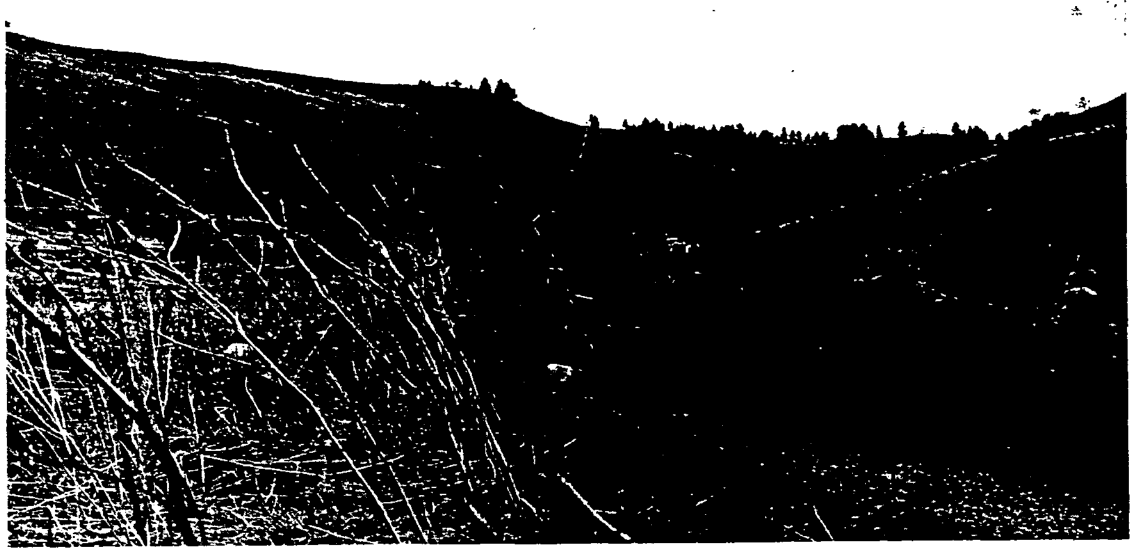


Photo 31: Erosion on trail crossing area with thin surficial materials covering Pierre Shale.

Photo 32: Paved trail near Doudy Draw access.



Areas of Special Geologic Concern

Based on geologic hazards or concerns and on geologic resources, several areas in the Eldorado Mountain Management Area warrant special attention relative to management policies. These include:

- Dakota ridge areas like those on the Lindsay property that have high steep walls of ripple rock exposed by clay quarrying, exposed dinosaur tracks, and small wetlands at surface contacts between sandstones and fire clays (Photo 29).

- Seeps and springs in Doudy Draw at the boundary between Boulder County and Jefferson County (Photo 30). The surrounding bedrock is erodible Pierre Shale exhibiting numerous hillside seeps and incipient downslope slumping with the potential for mass movement and disruption of the drainage and wetland.

- The former Conda quarry site (Photo 25) combines steep natural walls prone to rockfall, oversteepened quarry walls, unconsolidated quarry fill with a high component of fine-grained material, a water pipeline positioned above the fill, a location proximal to faults, and a position perched at the head of a steep ravine overlooking Eldorado Springs.

- Trail traffic and trail-cuts that alter the natural grade of the land both leave nonresistant rock units such as the Pierre Shale susceptible to excessive erosion and potential destruction of the adjacent landscape (Photos 31 and 32). The floor of Doudy Draw and the access area at Flatirons Vista are examples of areas where nonresistant rocks are exposed at the ground surface. In similar areas and where nonresistant rocks are covered only thinly with alluvium or colluvium, they are also highly susceptible to these effects. Where they are exposed in hillsides or in seep areas, these rock units are also susceptible to slumping and sliding.

Data Gaps

Geologically unique, fragile, and exemplary paleontologic, sedimentologic, and mineralogic features need to be systematically catalogued in areas of special concern. Their current condition and the risk factors affecting them need to be assessed, and the desirability of protection and preservation, as well as best methods for protection or preservation, need to be investigated.

Existing wetland studies need to be linked to geological and hydrological studies and ideally should be augmented by water quality studies.

Areas with high potential for mass movement should be catalogued and considered relative to trail development.

Glossary

alluvium - unconsolidated eroded material including rock, earth, and associated debris whose deposition was controlled primarily by flowing water (includes deposits in stream beds, floodplains, alluvial fans, colluvium reworked by streams, etc.)

aquifer - subsurface rock unit through which groundwater travels relatively easily; compare with: **aquitard** - subsurface rock unit that slows or impedes the flow of groundwater and: **aquiclude** - subsurface rock unit that prevents or greatly inhibits the flow of groundwater

bedrock - solid rock exposed in outcrops or lying beneath unconsolidated surficial deposits

colluvium - unconsolidated eroded material including rock, earth, and associated debris deposited mainly during downslope movement controlled primarily by gravity (includes debris on talus slopes, debris from slow downslope creep, debris on terrace or mesa slopes - commonly including alluvial material that has been eroded from the mesa tops, etc.)

fault - break or fracture in rocks with significant displacement of the rock on one side of the fault relative to the rock on the other side of the fault

joint - break or fracture in rocks without significant displacement of rock along the fracture; often form joint sets that display a relatively consistent related arrangement of fractures (e.g., radial joint set or vertical joint set)

mass movement - transport of significant volumes of rock and/or unconsolidated material with gravity as a primary control: includes **rockfall** (rock debris in relative free-fall from cliff), **landslide** (rapid downslope fall or slide of rock or earth), **debris flow** (rapid downslope flow of saturated earth & rock), **slump** (downslope collapse of surface and near-surface material on hillside or slope, with slumped rock and/or earth moving as a whole or in discrete pieces), **creep** (slow downslope flow of loose rock & earth), etc.

outcrop - bedrock without surficial cover, exposed at the earth's surface

pediment - planar erosion surface cut into bedrock, thinly covered with alluvium, and sloping gently away from the mountain front and toward the plains

shear zone - area where multiple faults and fractures have produced crushed, brecciated rock

surficial deposits - soil and unconsolidated deposits such as alluvium and colluvium that cover underlying bedrock

talus - sloped deposit of loose rock debris at the foot of a cliff

unconformity - surface separating significantly younger rocks from older rocks and representing time missing from the rock record due to erosion and/or nondeposition during that time span

References

Bilodeau, S.W., Van Buskirk, D., and Bilodeau, W.L., 1987, Geology of Boulder, Colorado, United Sates of America: Bull. of the Assoc. of Engg. Geologists, v. XXIV, no. 3, p. 289-332.

Bryant, B., McGrew, L., and Wobus, R.A., 1981, Geologic map of the Denver 1° x 2° Quadrangle, north-central Colorado: U.S. Geol. Survey Misc. Inv. Series Map I-1163.

Malde, H.E., 1955, Surficial geology of the Louisville Quadrangle, Colorado: U.S. Geol. Survey Bull. 996-E, p. 217-257.

Scott, G.R., and Cobban, W.A., 1965, Geologic and biostratigraphic map of the Pierre Shale between Jarre Creek and Loveland, Colorado: U.S. Geol. Survey Misc. Geol. Inv. Map I-439.

Spencer, F.D., 1961, Bedrock geology of the Louisville Quadrangle, Colorado: U.S. Geol. Survey Geol. Quadrangle Map GQ-151.

Trimble, D.E., and Fitch, H.R., 1974, Map showing potential gravel sources and crushed-rock aggregate in the greater Denver area, Front Range urban corridor, Colorado: U.S. Geol. Survey Misc. Inv. Series Map I-856-A.

Wells, J.D., 1967, Geology of the Eldorado Springs Quadrangle, Boulder and Jefferson Counties, Colorado: U.S. Geol. Survey Bull. 1221-D, p. D1-D85.