Front Range Geologic Hazards Field Trip

Wednesday, October 11, 2000
Earth Science Week

Colorado Geological Survey
1313 Sherman Street, Room 715
Denver, CO 80203
(303) 866-2611

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Acknowledgements

Most of the concepts presented here have been extracted from a full-day field trip we led for a professional geological organization, the Geological Society of America (GSA) in October 1999. We have simplified the trip to include fewer stops, and have changed the format to make this guidebook more accessible to the non-geologist. Those looking for more detail and a larger number of stops are encouraged to procure GSA Field Guide 1, "Colorado and Adjacent Areas," which contains our original published guidebook. A citation of that article is as follows:

Noe, D.C., Soule, J.M., Hynes, J.L., and Berry, K.A., 1999, Bouncing boulders, rising rivers, and sneaky soils – a primer of geologic hazards and engineering geology along Colorado's Front Range, in Lageson, D.R., Lester, A.P., Trudgill, B.D., eds., Colorado and adjacent areas: Geological Society of America, Field Guide 1, p. 1-19.

The discussion sections are derived from a field trip that was given for the Dartmouth Alumni Association Rocky Mountain Section, in September 2000. David Noe, CGS, and David Abbott, a consulting geologist and member of the American Institute of Professional Geologists (AIPG), led the trip. The discussion items are Mr. Abbott's brainchild, and we thank him for granting permission to draw from them for this guidebook.

Special thanks go to Paul Sibley and Bill Robba for generously allowing us to access their land at the Marshall coal mines (Stop 6).

We would like to thank Vince Matthews, CGS Senior Science Advisor, for setting up this year's Earth Science Week field trips, and for providing support and assistance for the field trip itself. Write-ups for other CGS field trips can be found at www.dnr state.co.us/geosurvey.

Earth Science Week

Earth Science Week is a national observance that celebrates the study of geology and other Earth sciences. In his Congressional Resolution, Senator Ron Wyden (D-Ore.) stated the purpose of Earth Science Week, to recognize "…the important role played by the Earth sciences in expanding our economy, supporting our national goals, and increasing our knowledge of the larger world." President Clinton has also issued an Earth Science Week 2000 message.

In Colorado, Earth Science Week is recognized by a proclamation signed by Governor Bill Owens. The week is marked by public and classroom presentations and field trips led by the Colorado Geological Survey, the U.S. Geological Survey, the Friends of Dinosaur Ridge, and other professional Earth science organizations.

Earth Science Week occurs annually during the second full week of October. Its primary sponsor is the American Geological Institute. For more information, see AGI's web site at www.earthsciweek.org.

Introduction

The purpose of this field trip is to look at the geology of the Front Range foothills between Golden and Boulder, Colorado. The foothills are the place where two major physiographic regions meet, the Great Plains and the Rocky Mountains.

The complex interplay of geology and climate has resulted in a dramatic landscape of great beauty, making the Front Range foothills a desirable place to visit and live. Today, most of Colorado's residents live in cities along these foothills.

Although the landscape here looks timeless, it is not at all dormant. The foothills region is slowly but actively changing due to a number of geologic and climatic processes. Its mountains and mesas are wearing down, and water is eroding sediment from the rock. These processes are natural, and they have been occurring for millions of years.

We especially want to look at how geology impacts our daily lives in Colorado. Consider this: everyone interacts with geology. It's impossible to avoid it. Geology – soil and rock – is the literal foundation of where we live, where we work or go to school, and everywhere in between.

If we ignore geology, or if we do something to speed up a naturally occurring geologic process, there may be serious consequences. A *geologic hazard* is a situation that happens when people get in the way of a geologic process. The result may be damage to property or it may even be life threatening.

We will look at several examples of geologic hazards on today's trip. At each of the six stops, we will showcase a particular geologic situation by describing the basic geologic process and giving a history of what has happened there. This guidebook contains a basic write-up for each stop. Also, we have included some discussion points that focus on balancing the needs of society and the realities of an active geologic landscape.

For More on Geologic Hazards

The Colorado Geological Survey carries several good books on geologic hazards. For a general overview, we suggest "The Citizen's Guide to Geologic Hazards" (Publication MI-57) and "Home Buyer's Guide to Geologic Hazards" (MI-58).

For Colorado's geologic hazards, we suggest "Nature's Building Codes: Geology and Construction in Colorado" (SP-12). The CGS also carries books on specific geologic hazards (e.g., swelling soils) as well as site-specific investigations. See our web page at www.dnr.state.co/geosurvey for other information.

The U.S. Geological Survey carries a large number of maps and publications; however, some may be out of print. We suggest starting at their Geologic Hazards Team web page at geohazards.cr.usgs.gov.

Field Trip Route and Itinerary

We will visit six stops between Golden and Boulder. The field trip route is shown on a color map and given in tabular form (called a "Road Log") at the back of the guidebook. The Road Log gives detailed directions to all of the field trip stops, along with odometer mileage. The basic itinerary for the field trip is shown below.

The trip will be conducted "caravan style," meaning that we will take several vehicles. The lead vehicle driver will try to ensure that the caravan stays together. This may entail pulling off the roadway until everyone catches up. The drivers of the other vehicles should make sure that they keep up with the preceding vehicles, while heeding state and local traffic regulations.

Field Trip Itinerary

Meet between 8:00-8:15 a.m. in the parking lot at the eastern end of Parfet Park, Golden. The park is located at Washington Avenue and 10th Street. Leave the lot at 8:30.

Stop 1. CSM Student Housing (on Campus Road)
- Topic: Collapsing and swelling soils
- Presenter: Karen Berry

Stop 2. N. Table Mountain (in church parking lot at 1st and Ford Streets)
- Topic: Rockfall
- Presenter: Jim Soule

Restroom Stop, Loaf 'N Jug on Iowa Street, Golden

Stop 3. Leyden Gulch (on 82nd Avenue east of SH-93)
- Topic: Coal-mine gas storage facility
- Presenter: Dave Noe

Stop 4. Coal Creek Canyon (at Plainview Road)
- Topic: Alluvial terraces and flash floods
- Presenter: Jim Soule

Sack lunch stop along Coal Creek on Plainview Road.

Stop 5. Hwy 93 and 128 Junction (on SH-128 east of SH-93)
- Topic: Landslide terrain
- Presenter: Karen Berry

Restroom Stop, Conoco at Eldorado Spgs. Rd. or Safeway at Broadway/Table Mesa, Boulder

Stop 6. Marshall Coal Field (at Cherryvale Road)
- Topic: Coal mine fires and ground subsidence
- Presenter: Dave Noe

Return to Parfet Park in early afternoon, by 2:00 p.m.

Geologic Setting

For simplicity, we can think of the geology of the Front Range Foothills areas as falling into three basic categories of rock and soil deposits: "really old," "old," and "young." We have included a series of color maps and cross-sections that show these rock and soil deposits, in the back of this guidebook.

The "really old" deposits consist of the igneous and metamorphic rocks that make up the mountains in the Front Range itself. These rocks date back to the Precambrian era. Most of them are over 1 billion years old.

The "old" deposits consist of sedimentary rock formations: mostly sandstone and shale with some limestone and coal layers. These rocks date back to the Paleozoic, Mesozoic, and Cenozoic eras. They range in age from about 300 million years to 63 million years. These formations have been folded and uplifted by the Rocky Mountains along the foothills, whereas they are flat-lying beneath Denver.

Tilted layers of 300-million year old Fountain Formation sandstone along the old Moffat Road. These sedimentary rocks were originally flat; they were uplifted into their present position when the Rocky Mountains were formed about 65 million years ago. (Photograph by L.C. McClure, 1904. Courtesy Denver Public Library Western History Department)

The "young" deposits consist of unconsolidated (i.e., soil) sediment deposits that lay atop the older rock deposits. These sediments are alluvial (deposited by streams), colluvial (slope-wash), and eolian (wind). Many of these deposits date back to 1 million to 25 thousand years, when Colorado's mountains experienced several periods of glaciation and melt-off.

Stop 1 – Collapsing and Swelling Soils
Colorado School of Mines Student Housing, Golden

Location:

This stop is located on Campus Road, which runs along the western side of the Colorado School of Mines Campus. To get there from Parfet Park, turn left on 10th Street,left on Washington Avenue, right on 19th Street, right on Elm Street (onto the CSM campus), and left on Campus Road. Park near the large rock outcrop on the left (west) side of the road.

Site Geology and Land Use History:

This site is underlain by the Laramie Formation, which is Upper Cretaceous in age. It is made up of alternating layers of sandstone, claystone (shale), and coal. At this site, the layers have been tilted to nearly vertical as a result of the Rocky Mountain uplift.

Many of the claystone layers in the Laramie Formation have been mined. Refractory clays were mined to make ceramics, bricks, and other products. Our stop is the former location of the White Ash Mine. After mining ceased, the open stopes were used for years as a trash dump. Later, the site was reclaimed. Fill dirt was spread across the site and the CSM Student Housing area was constructed.

Geologic Hazard Highlights:

The student housing area is crossed by several substantial swales, some with over a foot of sag. The swales run parallel to each other in a north-south orientation. These swales can be followed directly into the outcrop to the north, where they join up with mined-out claystone beds.

We are looking at a classic case of *differential settlement*. The fill and trash in the old clay pits has collapsed, while the adjoining sandstone ribs are stable. Substantial damage has occurred to some of the student apartments that were founded partially over the fill. These apartments were repaired by installing steel beams over the fill, anchored on the sandstone ribs.

Discussion Points:

There are many reclaimed landfills around the Denver Metro area. Notable examples include the Denver Coliseum, Mile High Stadium, and the Cherry Creek Mall. In addition to differential settlement, leaking methane gas is another consideration for some reclaimed landfill sites.

Colorado has several types of *collapsing soils*. In this case, we are looking at settlement of human-made fill. Naturally collapsing soils include loosely packed deposits such as windblown sand and silt (loess), and water-laid debris-flows. Evaporite soils, containing gypsum, are prone to dissolution and collapse when wetted.

Swelling soils, which contain a clay mineral that expands forcibly when wetted, comprise Colorado's most costly geologic hazard in terms of property damage. They are found throughout the Front Range Urban Corridor, where most of the state's population resides.

Stop 2 – Rockfall
North Table Mountain, Golden

Location:

This stop is located in a church parking lot at the corner of Ford Street and 1st Street, in north Golden. To get there from Stop 1, backtrack along Campus Road and Elm Street, turn right on 19th Street, right on W. 6th Avenue (U.S. Hwy 6), go straight through the big intersection onto State Hwy 93, turn right on Iowa Drive/Street, right on Ford Street, and left into the church parking lot. Park in the lower, easternmost part of the parking lot.

Site Geology and Land Use History:

Looking east, we see the broad slopes of North Table Mountain. These slopes are covered with landslide deposits, which are underlain by the Denver Formation of Cretaceous-Tertiary age (the K-T boundary is hidden up there, somewhere).

The rimrock cliffs at the top of the mountain are the remnants of a series of 63-64 million-year-old lava flows. The lava originally flowed down a valley. After cooling, it became very hard and resistant to erosion. The surrounding highlands later eroded away leaving the former valley as today's high point. This type of geomorphic feature is known as a *topographic inversion*.

The subdivisions on the lower slopes were built in the 1970s to 1990s.

Geologic Hazard Highlights:

Rockfall is an easy geologic hazard to visualize. It involves a rock outcrop, fractures or joints, a hillslope below, water (sometimes), and gravity. The hillside on North Table Mountain, below the rimrock, is covered with lava boulders from top to bottom. The freshness of the boulders indicates that many of them were moved by falling rather than by "surfing" on the landslides.

Rockfall is a difficult geologic hazard to predict because of uncertain timing of occurrence of rockfall events and the errant nature of a rolling rock's trajectory. Although catastrophic rockfall is not likely here, it only takes one errant boulder to cause serious damage or take a life. We can only guess that a rockfall incident will occur sometime, we just can't say when that will be.

Discussion Points:

Jefferson County considers the slopes of North Table Mountain to be off-limits to development, based upon rockfall-hazard mapping done by the U.S. Geological Survey in the 1970s. The City of Golden has chosen not to recognize this rockfall-hazard zone. As the city annexes more land along the slopes, more houses are built in this area of marginal safety.

Rockfall is a critical hazard along Colorado's mountain highways, and in towns such as George-town, Vail, and Telluride. It is virtually impossible to eliminate the hazard because new rocks are always being loosened by erosion. However, geologic and engineering researchers have developed intriguing designs for rockfall fences and protection walls over the past few decades.

Stop 3 – Gas Storage Facility
Leyden Gulch, Jefferson County

Location:

This stop is located on 82nd Avenue near the old mining town of Leyden, about 8 miles north of Golden. To get there from Stop 2, backtrack on Ford Street and Iowa Street, turn right on State Hwy. 93, drive about 6 miles, turn right on 82nd Avenue (at the "Leyden" sign). Drive past the vertical spires of Laramie Formation sandstone, then a mile farther. Park in front of the Public Service Company of Colorado (PSC) substation, a green-roofed, metal shed surrounded by a chain-link fence.

Site Geology and Land Use History:

The grass-covered slopes along Leyden Gulch are underlain by small landslide deposits and flat-lying Denver Formation. The Laramie Formation is exposed as vertical beds of sandstone and claystone a mile to the west, where we entered the valley (did you notice the clay mines?). At our stop, the Laramie Formation is flat-lying and nearly 500 feet below us.

The Leyden Coal Mine is located within the Laramie Formation beneath the entire valley. The mine was active during the early 20th century. Decades later, PSC began using the mine to store natural gas. PSC installed a number of charge wells and withdrawal wells around the valley. Up to 3.5 billion cubic feet of gas can be stored in the mine. Gas is bought and stored in the mine during summer when the gas can be purchased at a lower price. During winter, the gas is withdrawn and used to "surge" the supply system for peak demand at lower cost to consumers.

Geologic Hazard Highlights:

The Leyden Mine served as a successful gas storage facility for many years, primarily because it is located at great depth and is covered by hundreds of feet of saturated, "tight" shales. With time, however, it appears that leaking gas may have broken through to the ground surface at nearby private properties. In 1999, PSC was involved in a major court case over gas leakage. Subsequently, PSC has decided to close the facility.

Discussion Points:

This facility is the only one of its kind in the world. Unfortunately, this is a problem because there is no precedent for closing such a facility. Currently, the Colorado Oil and Gas Conservation Commission and the Colorado Public Utilities Commission are in a deadlock over this issue; neither entity wants to be the primary overseer of the closure. Now that PSC has lost its major surge-storage facility, where will it build replacement facilities? Above-ground facilities are risky in themselves, and likely to be unpopular wherever they are planned. As consumers, how much will this loss of storage affect our pocketbooks?

This entire area is under considerable land-development pressure. There are many geology-related questions about the effectiveness of the facility's closure and other public-safety issues that will need to be answered before development can proceed here.

Stop 4 – Alluvial Terraces and Flash Flooding
Coal Creek Canyon, Jefferson County

Location:

This stop is located on Plainview Road near the mouth of Coal Creek Canyon. To get there from Stop 3, backtrack on 82nd Avenue, turn right on State Highway92, left on State Highway 72, and right on Plainview Road after about 1-3/4 miles. Drive down the hill and park near the bridge at the creek crossing. We will eat a sack lunch here.

Site Geology and Land Use History:

We are at the apex of a broad, ancient alluvial fan that spreads out toward the Plains to the east. This deposit is known as the Rocky Flats Alluvium. It contains numerous boulders near the apex and more sand and gravel towards its outer margins. The fan surface has been exposed for nearly a million years, yet it has not eroded away as quickly as alluvial terraces elsewhere. The secret: the mountains to the west are composed of very hard quartzite (a metamorphic rock), and the quartzite boulders that were deposited in the alluvium are quite resistant to erosion.

Coal Creek Canyon is similar to other stream-carved canyons along the Front Range. It has cut through relatively hard igneous and metamorphic rocks, resulting in a steep, narrow canyon. The creek gradient flattens and the floodplain widens as it leaves the mountains and enters the Plains.

Geologic Hazard Highlights:

Many streamside areas in Colorado have been subject to devastating *flash floods* over the last century-and-a-half. This has occurred not only in the constricted mountain canyons, but also on the broad, sandy, nearly ephemeral streams on the Plains. These floods are mostly driven by significant rainfall events, and are occasionally augmented by snowmelt.

The greatest historical flood along Colorado's Front Range occurred in the Big Thompson Canyon in 1976. An isolated thunderstorm dropped up to 12 inches of rain on parts of the basin, resulting in a peak flow of 39,000 c.f.s. An estimated 139 people were killed during the flood. Afterwards, the CGS documented many off-channel events including debris avalanches, debris flows, ephemeral-streambed scour, deep sheet erosion, and significant off-channel deposition.

At the mouth of Coal Creek Canyon, we can see a sequence of *paleo-flood deposits* produced by events similar to the Big Thompson flood. The youngest is about 955 +/-80 ybp (C-14 dating).

Discussion Points:

Flood-control dams are touted by some as the only viable protection from larger floods. Such dams are not popular, however, and they do not protect anyone living upstream from the dam.

When an area is developed, there is a significant increase in surface runoff, and a shortening of the peak runoff period, because of impervious surfaces (roads, sidewalks, roofs, etc.). This is a big issue for rapidly developing areas, as exemplified by Fort Collins and Colorado Springs.

Stop 5 – Landslide Terrain
Highway 93 and 128 Junction, Boulder County

Location:

This stop is located about ½ mile east of the junction of State Hwys. 93 and 128, on State Hwy. 128. To get there from Stop 4, backtrack on Plainview Road, turn left on State Hwy. 72, left on State Hwy. 93, and continue for over 4 miles, entering Boulder County. Turn right on State Hwy. 128 and drive about 1/2 mile to a small road cut just before the crossing of Coal Creek. Park along the road cut and walk up the western embankment for the best views.

Site Geology and Land Use History:

Looking to the southwest from the highway embankment, there is a small hill about ½ mile away. The core of the hill is comprised of relatively flat-lying Laramie Formation, and the hill is capped by a thick deposit of Rocky Flats Alluvium.

Notice that the side of the hill looks somewhat like a rumpled carpet. This is a characteristic, *hummocky topography* that marks a *landslide* deposit. Here, we can see a small but well-formed, active landslide in the left-central part of a much-larger, older landslide. The active landslide has a pronounced *scarp* at the top and a mound-like *toe* at its base. Note the green vegetation near the active landslide. This is a *seep* that is fed by groundwater flowing out of the alluvial deposit.

Geologic Hazard Highlights:

This particular landslide does not constitute a geologic hazard, at least at this time, because the land is undeveloped pastureland. However, there is similar landslide terrain in many areas of Colorado. Many of these landslides were active in the past, when there was a wetter climate.

Human development activities can inadvertently re-activate older, dormant landslides. Such activities include cutting the toe, loading the top, and increasing the amount of water that enters the landslide deposit. Some landslides fail soon after they are disturbed, while others take much longer. The long-term buildup of groundwater appears to be a factor in many landslide events. This buildup can occur naturally (as a result of several wet years or large precipitation events) or it can be partly or wholly human-influenced.

Discussion Points:

Hillside property in Colorado is often underlain by landslide deposits. Unfortunately, this same terrain comprises "view lots" that are very much in demand today. It is often difficult to prohibit development in risky, landslide-prone areas when high land prices are a factor. Several cities and towns, most notably Colorado Springs and Grand Junction, are currently grappling with landslide-related land-use issues.

If the rolling, hummocky topography reminds you of skiing, don't be too surprised. Many of Colorado's premier ski areas are located on landslide terrain. Ski areas and golf courses are actually appropriate uses for landslide-prone terrain.

Stop 6 – Coal Mine Fire and Subsidence
Boulder-Weld Coal Field, Marshall

Location:

This stop is located on Cherryvale Road, east of the old mining town of Marshall. To get there from Stop 5, backtrack and turn right on State Hwy. 93. After nearly 2 miles, turn right on State Hwy. 170 (at the Marshall/Eldorado Road junction), right at the stop sign, and left on Cherryvale Road. Park in the triangle of grass just north of the turnoff.

Important notice: We will be crossing onto private property to access this site. Please do not disturb or remove anything from these historical mining properties.

Site Geology and Land Use History:

This site is located on an outcrop of gently dipping, Laramie Formation sandstone. Beneath the outcrop is a sequence of interbedded sandstone and coal layers. There are several small faults in this area. They were apparently active nearly 68 million years ago when the formation was being deposited, as evidenced by coal seams that thicken or thin markedly between fault blocks.

Marshall is the westernmost of a series of towns located along the Boulder-Weld coal field. These towns (Superior, Louisville, Lafayette, Erie, Frederick, Firestone, and Dacono) were originally mining towns. More recently, they have become bedroom communities during the booming economic times of the 1990s.

Geologic Hazard Highlights:

The most obvious ground feature in this area is a series of elongate, box-like depressions. These mark the location of former rooms in the coal mine that have collapsed. The pattern is distinct here because the mine was shallow (30-40 feet deep) and there is little to no soil cover. This is yet another example of *differential subsidence*. A few houses in Louisville and other nearby towns have experienced sinkholes opening directly above deeper, collapsing coal-mine rooms.

Walking across this area, it is possible to detect steam and sulfur-laden vapors rising from the ground. A smoldering fire has been burning in the underground coal seams near Marshall for several decades. This fire has resulted in addition coal-seam collapse and ground settlement. Significant remedial work has been done to the nearby irrigation culvert to protect its structural integrity. Near State Hwy. 93, a large earthen berm was built to choke off the fire's air supply and protect the highway from settling.

Discussion Points:

The coal-mine fire and subsidence have imposed considerable land-use constraints on the Marshall area. Houses have been sited on a lot-by-lot basis by carefully locating unmined pillars and the limits of mining. Boulder County has acquired a large amount of land in the area for use as open space, thus avoiding future development problems.

Conclusions and Final Thoughts

That's it for today's field trips. At Marshall, the participants are free to drive back to Parfet Park in Golden (via State Hwys. 93 and 58 and Washington Avenue), or elsewhere if they choose.

We hope that we have shown you how the knowledge of geology is a critical factor in land-use planning and geologic-hazard recognition and mitigation. This is especially true under the rapid growth conditions that are being experienced in Colorado today.

The Colorado Geological Survey is charged with providing geologic evaluations and information to Colorado citizens and other government agencies. Leading public field trips like this one is but one of the ways we strive to meet this charge. We also conduct scientific research on many types of geologic topics, publish reports and maps, maintain a web site, host statewide geologic-hazard conferences, and respond to questions posed by the public.

If you have any questions or comments about the field trip or this guidebook, please call any of the field trip leaders or Vince Matthews, CGS Senior Science Advisor, at (303) 866-2611.

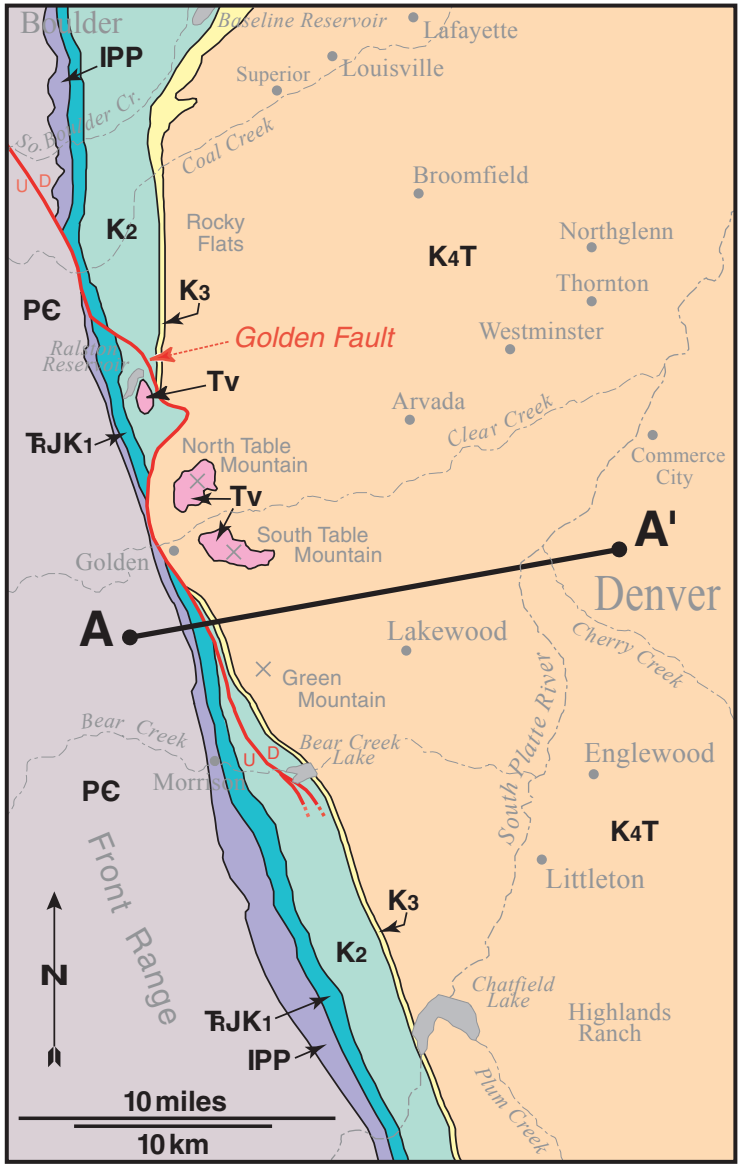
Did You Also See…

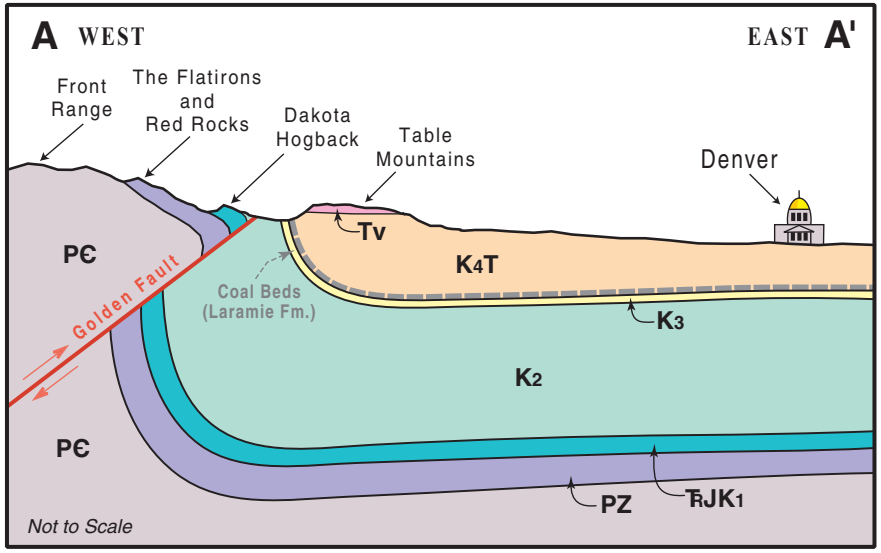
The numerous clay mines along the hogback ridges along State Hwy. 93?
The mines to the east are in the Laramie Formation, while those to the west are in the Dakota Sandstone.

The new Jefferson County football stadium near 68th Avenue?
The stadium was originally planned to be dug into the hillside to the south, but geologic concerns (swelling bedrock and faulting) caused its location to be moved to a more benign location. It cost more to build the stadium there, but the long-term maintenance costs are anticipated to be lower.

The railroad curves in the upper valley of Leyden Gulch?
These curves utilize the natural geologic landscape, climbing out of the valley onto a flat alluvial terrace. The hopper cars on the upper curve are a permanent fixture. They are filled with ballast and serve as a windbreak to keep trains from being blown off the track. Winds of over 100 mph are possible here.

The ruins of the Matterhorn Restaurant at the Boulder Valley overlook?
Also known as "Boulder's Stonehenge," this restaurant burned, twice, due to kitchen fires. A factor in the destruction from each fire was that there was an inadequate supply of water. The site is located on Pierre Shale, which is "tight" (low permeability) and a poor source of groundwater. The restaurant had relied on shallow groundwater from the Rocky Flats Alluvium, collected in a cistern.



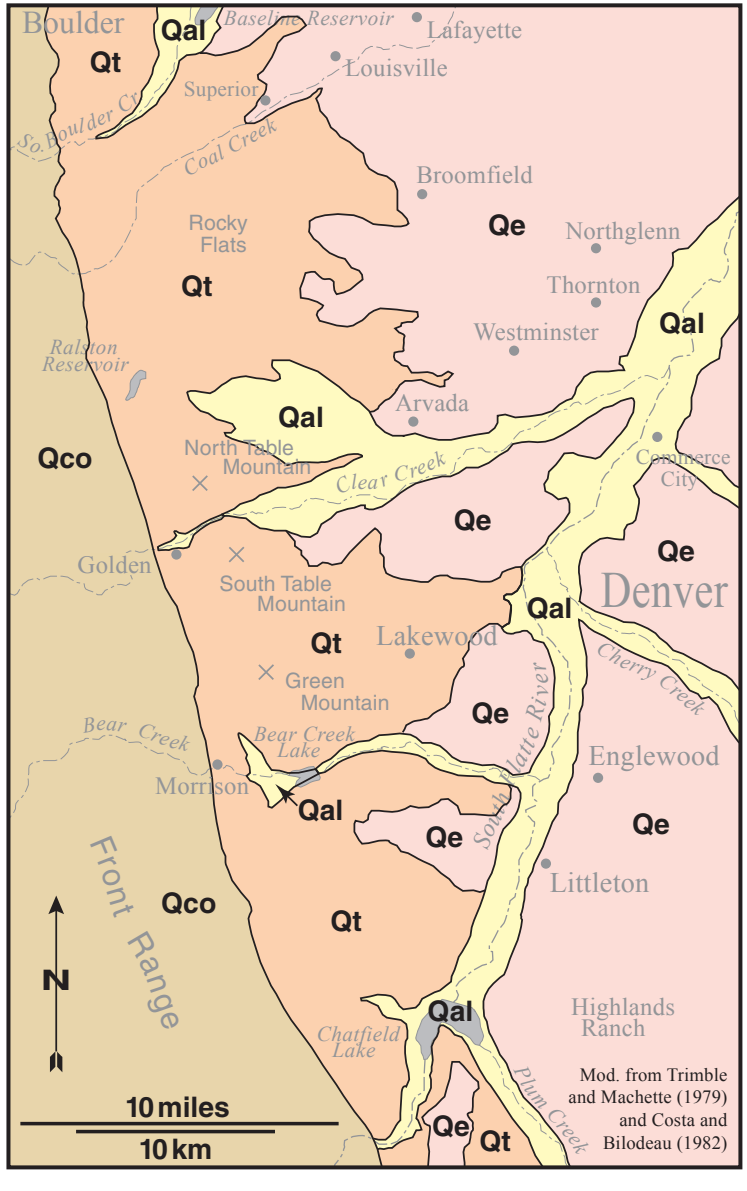


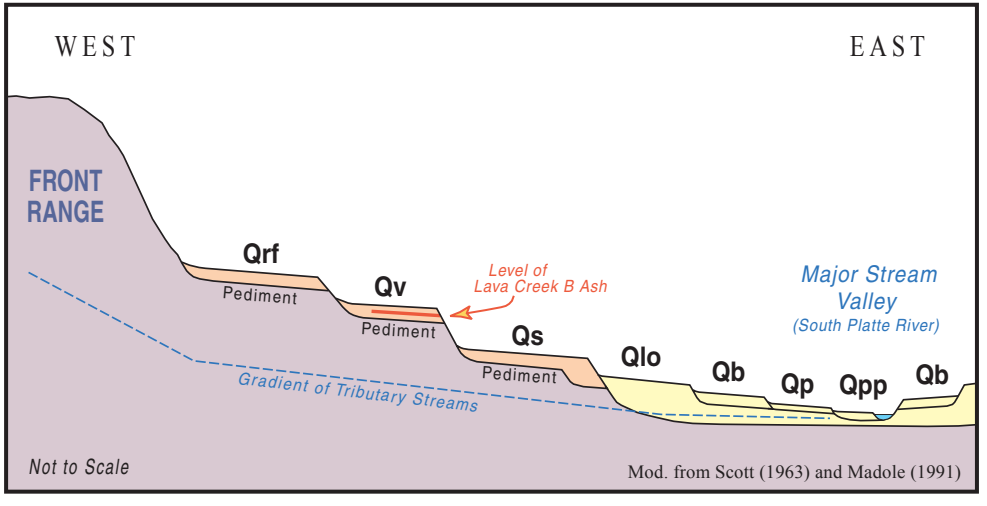
Bedrock Map and Cross-Section

Tv	Tertiary Volcanic Rocks
K4T	Laramie, Arapahoe, and Denver Formations
K3	Fox Hills Sandstone
K2	Benton, Niobrara, and Pierre Shales
TrJK1	Morrison Formation and Dakota Sandstone
IPP	Fountain and Lyons Formations
PC	Precambrian Igneous and Metamorphic Rocks

T - Tertiary, K - Cretaceous, J - Jurassic, Tr - Triassic, P - Permian, IP - Pennsylvanian, PC - Precambrian

Mod. from Wells (1967), Van Horn (1972), Trimble and Machette (1979), and Costa and Bilodeau (1982)





QUATERNARY ALLUVIAL DEPOSITS

(Listed from oldest to youngest)

Older alluvial terraces

Qrf	Rocky Flats (Aftonian/Nebraskan)
Qv	Verdos (Yarmouth/Kansan)
Qs	Slocum (Sangamon/Illinoian)

Younger alluvial valley fills

Qlo	Louviers (Bull Lake)
Qb	Broadway (Pinedale)
Qp	Piney Creek (Holocene)
Qpp	Post-Piney Creek (Holocene)

QUATERNARY GEOLOGY

(Predominant type of deposit is shown)

Qe	Eolian deposits (sand and loess)
Qal	Younger alluvial valley fills
Qt	Older alluvial terraces on pediments
Qco	Colluvial and residual deposits

FIELD TRIP ROUTE AND STOPS