A Brief Summary of Boulder Geology

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Introduction

Rock units exposed at the earth's surface are called **outcrops**. Rocks and surface deposits exposed in the Boulder area represent a time span of about two billion years. The order in which the rocks formed, from oldest to youngest, is called a **stratigraphic sequence**.

The stratigraphic sequence is divided into rock units that have different names. **Formations** are rock units that are thick enough and widespread enough to be drawn onto a topographic map. Formations can be further divided into **members**, which are distinctive widespread units within the formation. Individual depositional layers within a formation or member are called **beds**. In some cases, formations are lumped together into larger units called **groups**.

Groups, formations, and members are **named for geographic sites** where they are well exposed in outcrop. For example, the Fountain Formation was named from outcrops along Fountain Creek near the town of Manitou Springs, Colorado. Some formation names are used only locally, but others are used over wide geographic areas. The name "Dakota" is used for Cretaceous rocks in North Dakota, South Dakota, Montana, Wyoming, Nebraska, Kansas, Oklahoma, and New Mexico, as well as Colorado. Sometimes a name that seemed appropriate at a particular location is later replaced. This was true in our area for the white sandstone we now consider part of the Sundance Formation. It was once referred to as the Entrada Sandstone but was renamed because its origin is more closely tied to the Sundance Formation of Wyoming than to the Entrada Sandstone of Utah and western Colorado.

The site where a particular formation is well exposed and was officially described is called its **type section**. The type section is usually, but not always, near the locality where the formation was named.

A **contact** is the surface along which two distinct rock units meet each other. A contact may be between any two rock units - two formations, two members, or two individual beds. For example, the surface where the younger Dakota Formation meets the older Morrison Formation is the "contact" between the two formations. The surface between a sandstone bed and a shale bed *within* the Dakota Formation is the "contact" between those two beds. Some contacts are sharp; others are gradational. Contacts are referred to as interfingering or intertonguing when layers of rock typical of a younger rock unit alternate with layers typical of an older rock unit. A contact may represent virtually no "missing" time, or it may represent significant - sometimes enormous - time for which no rocks are preserved. A contact which represents a great deal of missing time is known as an **unconformity**.

Summaries

The following paragraphs very briefly describe geologic events and conditions in the Boulder area.

2,000-1,800 mya ("millions of years ago")

Processes

A thick sequence of interbedded sedimentary and volcanic rocks formed while our area lay near the southern margin of an ancient Precambrian continent. Details of their deposition are hard to unravel because these rock units have since been metamorphosed.

1,800-1,650 mya

Processes

Two Precambrian periods of **intense deformation and regional metamorphism** changed the earlier-formed sedimentary and volcanic sequence into metamorphic rocks now known as the **Idaho Springs Formation**. Among the rock types are schist, gneiss, quartzite, and metaconglomerate.

Closely associated with the metamorphism, particularly in its later stages, were large volumes of **deep magma** that pushed into the overlying rocks to form intrusive bodies called batholiths. The magma **cooled at depths of 10 to 15 miles** without reaching the earth's surface. The **Boulder Creek Granodiorite**, which formed in this way, is mostly granodiorite and quartz monzonite but includes rocks that range in composition from gabbro to granite.

Names and Exposures

The Idaho Springs Formation was named for exposures near Idaho Springs, Colorado. Near Boulder, these rocks are fairly well exposed in Lefthand and Boulder canyons. There are more extensive outcrops to the south in Coal Creek and Clear Creek canyons.

The Boulder Creek Granodiorite was named for exposures along Boulder Creek. It is well exposed in Boulder Canyon and on top of Flagstaff Mountain. In some places, it contains **xenoliths** ripped from the Idaho Springs Formation as the magma pushed through the older rock.

1,450-1,350 mya

Processes

The Precambrian **Silver Plume Granite** (also called the Silver Plume Quartz Monzonite) formed as much as 10 miles beneath the earth's surface. It was part of a **quiet subsurface upwelling of deep magma** that formed a number of batholiths, including the St. Vrain Batholith to the northwest.

Names and Exposures

The Silver Plume Granite was named for exposures at the old mining town of Silver Plume in Clear Creek Canyon south of Boulder. It is well exposed in the canyon west of Hall Ranch.

1,700 (and before) - 1,200 mya

Processes

Starting at least as early as the metamorphosis of the rocks in the Idaho Springs Formation, continuing throughout the development of the Boulder Creek and Silver Plume batholiths, and probably extending for another two million years beyond that, four major belts of brittle fractures developed in the igneous and metamorphic rocks that were forming beneath what is now Colorado. Three of these **Precambrian shear zones**, each containing many sets of faults and fractures, extend hundreds of miles across Colorado and into neighboring states. Throughout Colorado's geologic history, the shear zones have been continuing zones of weakness along which episodes of deformation, igneous intrusion, and/or mineralization have occurred. The shear zones continue to exert a strong influence on Colorado geology and topography to this day.

Two of the shear zones cross west of Boulder. The trend of the older zone runs just a little northwest of north. There is evidence that it was active even before the oldest preserved rocks were formed. This shear zone helped control the boundaries of central Colorado's ancient and modern north-south mountain ranges. The younger shear zone, also known as the **Colorado Lineament**, trends northeast across the state and runs through Central City; branches of it extend across Jamestown. This shear zone started to form very early, too, but it was best developed following emplacement of the Silver Plume batholith. Mineralized fault swarms within it are referred to as dikes or breccia reefs, with individual names such as Maxwell, Hoosier, and Poorman. The mineralization came during much later activity along the shear zone, mostly during the Tertiary Period, when mineral-bearing magmatic fluids moved up into the older rocks to form the ores of the Colorado Mineral Belt.

A third Precambrian shear zone runs just a little north of west across southern Colorado. Tertiary volcanism occurred along it in southeastern and southwestern Colorado. The volcanic San Juan Mountains developed at this shear zone's intersection with the Colorado Lineament.

A fourth shear zone enters northwest Colorado along the west-east trend of Utah's Uinta Mountains. Slightly metamorphosed rocks record sedimentary deposition about 1.4 to 0.95 billion years old.

1,050 - 1,000 mya

Processes

Precambrian **inclined dikes and nearly horizontal sills of fine-grained aplite and coarse-grained pegmatite** were intruded into the older Precambrian rocks. These are visible today in many areas, notably near the top of Flagstaff Mountain and in Boulder Canyon. These dikes are about the same age as the Pikes Peak Granite batholith near Colorado Springs and may have formed during the same intrusive event. Radiometric dating of rocks from the **kimberlite pipe** on Boulder's Green Mountain indicate that it formed at about the same time. The pipe was produced by a narrow, nearly vertical, violent volcanic explosion. The pipe contains microscopic diamonds and other mineral crystals embedded in a matrix of green and gray volcanic kimberlite rock.

Each of the Precambrian igneous intrusions in the Boulder area, starting with the Boulder Creek Granodiorite and ending with the pegmatite dikes and kimberlite pipe, appear to have been emplaced at a successively shallower depth than the preceding intrusion, suggesting that the region may have been undergoing uplift and erosion throughout this time.

1,000-330 mya

Processes

No rocks from the Cambrian, Ordovician, Silurian, Devonian, or Mississippian periods are preserved near Boulder. The Pennsylvanian Fountain Formation, deposited about 300 million years ago, lies directly on Precambrian rocks. The major **unconformity** that separates the Fountain Formation from the Precambrian rocks represents **as much as 1.4 billion years of "missing time."** The long gap in the rock record is due to nondeposition and/or erosion between Precambrian and Pennsylvanian time.

Even though there is no rock record preserved, we know some of what occurred during the very long interval represented by the unconformity. Since the sands, gravels, and muds that became the rocks of the Fountain Formation lie directly upon Precambrian rocks that formed miles and miles below the earth's surface, we know that a great deal of **uplift and erosion** occurred between the time the Precambrian rocks formed and the time that the Fountain Formation was deposited. From sandstones, shales, and limestones preserved in other areas of Colorado, we know that **shallow seas and low-lying landscapes** covered much of the state during part of the interval that is "missing" in Boulder.

Most of this interval is also missing from the rock record in north-central Colorado, and it once was thought that rocks of these ages were never deposited in this area. But evidence that they once existed was found in **diamond-bearing volcanic pipes** near the Colorado-Wyoming border. Toward the end of the "missing" interval of time, these volcanic pipes blasted their way to the surface from far below, causing chunks of the existing rock layers to sink down into the pipe. Some of these pieces of older rock are now preserved, trapped in the volcanic rock that hardened in the pipes. They include pieces of the rock layers which are now "missing" in the area. That means that at the time of the volcanic explosion, those layers were present in northern Colorado. Later, those layers were eroded away, but the pieces that had fallen deeper into the volcanic pipes were preserved. The magmatic fluids that formed the volcanic pipes contained a great deal of carbon dioxide gas. Its release during the explosive rise of the fluids kept their temperatures very low, almost near freezing by the time they reached the surface. As a consequence, detailed features of the rocks that fell into the pipes were preserved in many cases. Fossils in some of the rocks that fell into the pipes confirm that the pieces are from the time periods that are now "missing" from the rock record. Rocks from much of that interval are also preserved today around Colorado Springs. Because they existed both to the north and to the south, it is likely that they also were deposited and then removed by erosion in our area before the sediments that now form the Fountain Formation were deposited.

A well know locale for observing the unconformity between Precambrian and Paleozoic rocks is at "Contact Corner" on Flagstaff Mountain. There, the Fountain Formation lies on the Boulder Creek Granodiorite. The granodiorite is worn into crumbly rubble called **grus** (rhymes with "goose"). The presence of grus (and evidence suggesting an ancient soil on top) indicates that the Precambrian rocks were exposed and weathered at the earth's surface for a long time before the deposits that later became the Fountain Formation were laid down on top of them.

330-245 mya

Processes

By the **Pennsylvanian Period**, the continents of the earth were moving into each other as the ancient supercontinent of Pangaea was assembled. Mountain building was widespread. In our area, the Colorado Orogeny produced the **Ancestral Rockies**. The Ancestral Front Range almost paralleled the modern Front Range but lay about 30 miles farther to the west. Major mountain blocks also formed in central, southern, and southwestern Colorado. Relief on these mountains was comparable to the relief in today's Colorado mountains, but the whole region was much lower in elevation.

The **climate was arid. Erosion** of the Ancestral Rockies produced sediments that were deposited in broad, gently sloping **alluvial fans** similar to those flanking the dry ranges of Nevada today. Salt basins developed in southwestern Colorado and adjacent parts of Utah. Along the mountain fronts, alluvial fans formed broad debris aprons, or **bajadas**. In Boulder, the conglomerates, sandstones, mudstones, and shales of the **Fountain Formation** record deposition in alluvial fans.

During the **Permian Period**, erosion of the ancestral mountains continued. Shallow fingers of sea extended between Colorado's mountain blocks. Fields of coastal **sand dunes** developed along the eastern flank of the Ancestral Front Range; some of these are preserved in the **Lyons Sandstone**.

Names and Exposures

The Fountain Formation was named for exposures along Fountain Creek near Manitou Springs. In the Boulder area, the Fountain Formation is exposed along the mountain front in many places, including the Red Rocks outcrop off Mapleton Avenue, the dark purple-red outcrops at Buckingham Park, and the dark purple and gray outcrops high on the steep grade going up Lee Hill Road. Boulder's most famous exposure of the Fountain Formation is in the steeply tilted, eroded layers of the **Flatirons**. The mud, sand, and gravel that became these rock layers were deposited in nearly horizontal units; the folding and erosion that formed the Flatirons occurred hundreds of millions of years later.

Conglomeratic purple-red and dark-red rock units of the same age as the Fountain Formation are found along the flanks of the ancient mountain blocks that once stood south and west of us in areas such as the Red Rocks amphitheater at Morrison, the **Maroon Bells**, the Crestone peaks of the Sangre de Cristo Mountains, and the areas around Minturn and Hermosa. Tracks of small amphibians and early reptiles, as well as mud-filled casts of ancient trees have been found in the Fountain Formation.

The Lyons Sandstone was named for its exposures around the town of Lyons. The huge sloping **crossbeds** of the ancient dunes that formed the Lyons Sandstone are well exposed in the quarries at Lyons and along the Boulder foothills as well as in the road cut near the bottom of the steep grade up Lee Hill Road. In places, the sandstone contains ripple marks, raindrop imprints, and the fossilized tracks of small reptiles. The Lyons Sandstone is good building stone because its quartz grains and the silica cement that binds them together make it very resistant to weathering and because it splits smoothly along its flat bedding surfaces. Many of the buildings at the University of Colorado are built with Lyons Sandstone, and it is used nationally in sidewalks, patios, walls, table tops, and more.

245-208 mya

Processes

Pangaea persisted through much of the **Triassic Period**. While the continental masses were joined, some areas were elevated above sea level, and others were not. In the area that is now Colorado, only **isolated granitic knobs** remained where the Ancestral Rocky Mountains had been. Fingers of **shallow sea** covered some of the region. Mud, silt, and sand were deposited both in the sea and along its margins on **low-lying land**. The rocks of the **Lykins Formation**, which later formed from these deposits, are now orange or red in color due to the oxidation of iron-bearing clay minerals in the rocks. Within the Lykins Formation, a crinkly pink and gray limestone records the growth of **algal mats and mounds** which trapped small particles of sand and silt at the edge of the sea.

Names and Exposures

The Lykins Formation is named for exposures in Lykins Gulch a few miles north of Boulder. The Lykins Formation is also exposed at the junction of Lee Hill and Olde Stage roads. Because most of the rocks of the Lykins Formation are not very resistant, valleys develop along its outcrops. For much of its length, Olde Stage Road runs along a valley developed by erosion of the Lykins Formation. The Lykins Valley separates two ridges: the ridge to the west is capped by harder Lyons, Fountain, and Precambrian rocks; the ridge to the east is capped by resistant rocks of the Dakota Formation. The Lykins Formation itself is commonly covered by vegetation in the valley and is not very well exposed, but its orange-red color in soils and roadbanks is a clue to its presence. The thin crinkly limestone in the Lykins Formation is more resistant and commonly stands out as a small linear ridge within the valley, as it does in places along Olde Stage Road and on Heil Ranch.

208-144 mya

Processes

At the beginning of the **Jurassic Period**, small sand dunes formed along the low-lying coast while the shallow seas retreated from the area. These are preserved in the white sandstones of the **Sundance Formation**. An old name once used informally for this unit was the "Doctor Bond Sandstone" for a Boulder physician who tried unsuccessfully to quarry it for building stone (too soft!)

As the Jurassic period progressed, sand and mud were deposited across a wide area in **sluggish streams** and in the floodplains, swamps, and lakes that lay along them. These deposits later became the colorful purple, green, red and gray sandstone, siltstone and shale of the widespread **Morrison Formation**, famous for the fossilized **dinosaur bones** it holds in Colorado and adjacent states.

Names and Exposures

The Sundance Formation was named for exposures near the town of Sundance on the Wyoming-South Dakota border. The Sundance Formation is much more extensively developed in Wyoming, where the rocks record marine, shoreline, tidal flat, and wind-blown deposition. The Boulder area is the farthest-south extent of the Sundance Formation, and the best outcrop is in the ridge on the north side of Lee Hill Road a little east of the bend at Bow Mountain Road.

The Morrison Formation was named for exposures at Morrison, CO. Near Boulder, it is mostly covered by vegetation. It is better exposed on city open space south of Eldorado Springs along the old quarry road.

144-65 mya

Processes

During the **Cretaceous Period**, the Atlantic Ocean and Gulf of Mexico were growing wider as the North American continent continued to move farther from other continents. For much of the Cretaceous Period, the shallow **Cretaceous Seaway** covered the interior of the western United States and Canada as well as northeastern Mexico. Shorelines of the Cretaceous Seaway advanced and retreated a number of times, so that the sea alternately covered greater and lesser areas.

At its maximum extent, the Cretaceous Seaway **connected cold ocean waters from arctic areas north of today's Canada with warm ocean waters from the region of today's Gulf of Mexico**. The mixing of cold water fauna and warm water fauna, now preserved as fossils in the rocks of our area, shows that the northern and southern arms of the seaway met each other very close to Boulder.

At times, the seaway was as much as **1,000 miles across**. The shoreline west of Boulder was as far away as west-central Utah, and the shoreline to the east was as far away as eastern Iowa. The maximum depth of the seaway is debatable. Deepest estimates are around three thousand feet, but many researchers maintain that maximum depth was rarely, if ever, over a thousand feet and was much less most of the time. The rock record indicates that many areas of Colorado were at or very near shoreline more than once during the time the seaway dominated the region.

In Boulder, the oldest Cretaceous rocks are part of the **Dakota Formation**. At the "bottom" or oldest part of the Dakota Formation are conglomeratic sandstones deposited in and around **braided rivers**. These resistant layers are at the crest of the **Dakota Hogback** that forms the foothills skyline in north Boulder. Just younger than these are finer-grained sandstones deposited along the **shores of the advancing Cretaceous Seaway**. They are overlain by softer layers of dark shale and siltstone that form a little valley between the sandstone ridges at the "bottom" and "top" of the Dakota Formation. Younger than the shales and siltstones are shoreline and marine sandstones that form the smaller ridge downhill from the main Dakota Hogback toward the plains. These sandstones are part of the **Muddy Sandstone**, a member of the Dakota Formation.

The **Benton Formation** is just younger than the Dakota Formation. Its dark shales, calcareous shales, and thin limestones were deposited as the **seaway expanded** and reached its maximum extent. At the top of the Benton Formation is the **Codell Sandstone**. Near Boulder, the Codell Sandstone is often considered to be a member of the Benton Formation, but to the north and south it is an important (and better developed) unit in its own right. The Codell Sandstone represents deposition in **shallower water** than the rest of the Benton Formation. It frequently contains fossilized **shark teeth**. Both the

Benton Formation and the Codell Sandstone commonly have a "mixed" look due to the many **trails and burrows** left by shrimp and worms tunneling through and travelling across the sediments at the bottom of the seaway.

The **calcareous muds** that later became the **Fort Hays Limestone Member of the Niobrara Formation** developed when supplies of mud and sand from land were sharply reduced. When sediment supplies from the land were restored, the **muds and silts** that became the shales and siltstones of the **Smoky Hill Shale Member of the Niobrara Formation** were deposited. Many fossils of **marine clams and oysters** are preserved in the Niobrara Formation. The cross-section of one of these clam shells looks like tiny columns lined up in a row.

The **Pierre Shale**, just younger than the Niobrara Formation, is a shale-dominated unit with a few sandstone intervals. It is **up to 8,000 feet thick** and represents an extended period dominated by **marine deposition**. **Fossil clams, ammonites, and baculites** are common in the Pierre Shale. So are concretions, hard balls or discs of rock that developed in the sediments after deposition. The thickness of the mud that became the Pierre Shale is greater than the depth of the Cretaceous Seaway because the entire region was gradually sinking, or subsiding, so that as thick layers of mud built up, there continued to be "room" beneath the sea to deposit more mud.

At various times throughout the Cretaceous Period, **volcanic ash** was blown over wide areas when volcanoes erupted on land areas west of the seaway. The ash settled to the sea bottom in distinct layers that later became **bentonite clays**. Because bentonitic clays swell when they get wet, they can cause foundation damage to structures built on rock units that contain them. Bentonite beds appear as white, brown, rust, or pastel "stripes" that run along bedding. They are particularly noticeable in the Benton Formation, the Smoky Hill Member of the Niobrara Formation, and the Pierre Shale. Because the altered volcanic ash layers contain trace elements that other layers do not, the ash layers often support "special" suites of vegetation including some plants not found growing in other areas.

The **Fox Hills Sandstone** and the younger **Laramie Formation** were deposited at the end of the Cretaceous Period. They represent the final **withdrawal of the Cretaceous Seaway** from our area. The Fox Hills Sandstone was deposited along the margin of the retreating sea. The Laramie Formation includes sandstones, siltstones, mudstones, and **coals** that were deposited in lagoons, marshes and swamps, as well as in a few remaining brackish shoreline environments. The Laramie Formation also contains **plant fossils and dinosaur tracks**.

Names and Exposures

Because they were deposited in the broad Cretaceous Seaway, most Cretaceous rock formations are found over **wide geographic areas**, and their names come from a variety of places.

The Dakota Formation was named for outcrops in northwestern Nebraska while the area was still part of the Dakota Territory. The Dakota Formation is well exposed in the Dakota Hogback north of Boulder, but it is missing from south of Mount Sanitas (near Mapleton Avenue) all the way to the south side of Chautauqua Park. This is because the Dakota Formation, along with some less-noticeable rock units, has been faulted "out of sight" along the front margin of the foothills. Along the fault, formations younger than the Dakota Formation are now in contact with formations older than the Dakota Formation. Faulting disrupts the normal stratigraphic order of the rock layers in other areas, too, such as south of Boulder along Highway 93 and north of Boulder at Rabbit Mountain.

The upper sandstones of the Dakota Formation, known as the Muddy Sandstone, were named in a different way than most rock units. Rather than being named for a geographic location, the Muddy Sandstone is named for the muddy appearance of the rock cuttings that are produced by drilling through it in search of the oil and gas that both the Muddy Sandstone and other parts of the Dakota Formation contain. The Muddy Sandstone contains well preserved **ripple marks** and **dinosaur tracks** at Dinosaur Ridge along Alameda Road near Morrison. Dinosaur tracks, plants imprints, and root marks are common in the nonmarine parts of the Dakota Formation at many places in Colorado. The Dakota Formation produces **coal** and **oil and gas** in western Colorado and adjacent areas. Near Golden it was intensively quarried for refractory **fire clay** used in the manufacture of porcelains.

The Benton Formation was named for exposures near old Fort Benton, Montana. Other names often applied to parts of the Benton Formation, especially in southern Colorado, include the Graneros Shale, the Greenhorn Limestone, and the Carlile Shale. Each of these names comes from exposures near Pueblo, including those near Graneros Creek, the old Greenhorn railroad station, and Carlile Springs. The Codell Sandstone was name for outcrops near the town of Codell, Kansas.

The Niobrara Formation was named for outcrops along the Missouri River near the mouth of the Niobrara River in northern Nebraska. The Fort Hays Limestone and Smoky Hill Shale members are named for exposures along the Smoky Hill River near old Fort Hays in west-central Kansas.

The Benton Formation typically forms gentle grass-covered slopes with few exposures of rock. The lower units of the Niobrara Formation are more resistant: the Fort Hays Limestone typically forms low linear gray limestone ridges that weather to a very light gray. These are typically overlain by low brush-covered hills of the Smoky Hill Shale. Where drainages or roads cut through, black shales and much lighter calcareous shales and limestones are exposed. The uppermost units of the Smoky Hill Shale typically weather to an orangy-mustard color that can help identify its location in the field. The Benton and Niobrara formations are best exposed north of Boulder on the middle and lower eastern flank of the Dakota Hogback. Fractured units in the Niobrara Formation are drilled to produce **gas** in and around our area. The Fort Hays limestones are also quarried for use in **concrete and aggregate**.

The Pierre Shale was named for exposures near old Fort Pierre in South Dakota, although the exact location of the fort itself is no longer known. The Pierre Shale underlies much of the plains area downslope and east of the older Cretaceous formations. In some areas, notably near the town of Hygiene, sandstone units within the Pierre Shale form linear ridges. Where these sandstones are thicker, they have also been drilled to produce **oil and gas**. South of Boulder, the Pierre Shale is quarried for processing into **lightweight aggregate**.

The Fox Hills Sandstone was named for exposures in the Fox Hills of South Dakota. The Laramie Formation was named for exposures along the eastern flank of the Laramie Range in Wyoming.

The Fox Hills Sandstone and the Laramie Formation are exposed on both sides of Highway 93 near the Eldorado Springs turnoff south of Boulder. Farther south, on the east side of Highway 93 at Leyden Gulch, the Laramie Formation is tilted up on its edge along a fault. It looks like a volcanic dike, but it isn't. It forms an isolated ridge because the surrounding softer rock layers have eroded away. There are **palm tree imprints** and very faint **dinosaur tracks** in this outcrop.

The Fox Hills Sandstone is also exposed along South Boulder Road at the top of the hill outside Louisville. The Laramie Formation is exposed a little to the west, on the north side of South Boulder Road. The rust red color in the cut in the small hill there is from the burning of a coal seam in the Laramie Formation. The heat "cooked" and oxidized the surrounding rock layers to form clinker. Natural coal burns can start when lightning strikes coal beds exposed at ground level or when methane gas produced by organic matter in the coal ignites. Coal fires can burn underground for hundreds of years. The **coal** mined in Boulder County was produced from the Laramie Formation; rocks of the same age and slightly younger are mined for coal in other parts of Colorado and to the north and south. Regionally, the Laramie Formation also is quarried for **brick clay**.

70-50 mya

Processes and Exposures

Starting about 70 million years ago during the latest part of the Cretaceous Period and extending into the early part of the **Tertiary Period**, a new interval of mountain building called the **Laramide Orogeny** produced the **Laramide Rocky Mountains**. During this time, a series of **igneous intrusions and extrusions** occurred in our area. One of these produced **Valmont Dike**, the "wall" of rock along Valmont Road just east of Boulder. Along both sides of the dike, **contact metamorphism** is visible in the Pierre Shale where it was bent and baked as the rising magma pushed through.

Between Boulder's Flagstaff Mountain and Lyons, many **igneous sills** were intruded into Paleozoic and Mesozoic rocks of the foothills. Some of these felsite sills form light-colored crystal-bearing ledges high on the Dakota Hogback north of Boulder. Hornfels and black shales along the sills in the

Dakota Formation were baked by contact metamorphism. The basaltic layers on Table Mountain near Golden formed from lava flows during this interval.

The ancient Precambrian shear zones once again actively influenced geologic events. Mineralization occurred along the northeast-trending Colorado Lineament in the **Colorado Mineral Belt** when molten magmatic fluids containing metallic elements intruded the older rocks within the shear zones.

During and following the Laramide Orogeny, erosion in the mountains produced sands and gravels which were deposited in intermontane basins and on the eastern plains. None of the resulting Tertiary rock units are preserved in Boulder today, but the **Arapahoe Formation** and the **Denver Formation** are preserved south of Boulder. They contain both stream deposits and volcanic deposits. The "K/T boundary" between the Cretaceous and Tertiary periods, representing a time of widespread extinction, including that of the dinosaurs, lies within this interval. The Arapahoe Formation is named for outcrops in Arapahoe County; the Denver Formation is named for outcrops near the city of Denver.

50-9 mya

Processes and Exposures

Through-flowing drainage systems were poorly developed. The existing sluggish streams could not carry away most of the material being eroded from the Laramide Rockies. Eroded material collected in intermontane lakes and basins. Lake deposits that would later become **oil shale** were deposited in northwestern Colorado until about 40 mya. By then, the uplands of the Laramide Rockies had been severely eroded, the **intermontane basins were filling with eroded debris**, and the **topography was dominated by low rolling hills and plains** rather than by sharply defined mountains. **Volcanoes**, however, were active to the west and south at Spanish Peaks, Crested Butte, Gunnison, Mt. Sopris, the Elk Mountains, and the San Juan Mountains. **Lava flows** were active in northwest Colorado in the FlatTops and North Park and in southwest Colorado in the area of the San Juan Mountains and the Rio Grande River. Additional **mineralization** took place along the shear zones of the Colorado Mineral Belt. Except for the ores, no rock units of this age are preserved in the Boulder area.

9-1.5 mya

Processes

During this interval, an additional pulse of uplift raised the entire western U.S. from the Sierra Nevadas to the Front Range, **elevating the Front Range by at least 5,000 feet**. In many areas, **deep canyons** such as the Black Canyon of the Gunnison were cut as rivers responded to the uplift. Most remaining older sedimentary **rocks were eroded from the highlands**, although remnants can be found in the high mountain "parks" (South Park, Middle Park, North Park) and at scattered localities between. One example is an outcrop of the Dakota Formation, with marginal marine sandstones and shales, now "stuck" high in the mountains along the north side of I-70 near the Breckenridge exit.

Increased precipitation and massive seasonal snowmelt from the highlands helped transform the sluggish drainage systems into **large through-flowing river systems** including the South Platte, Arkansas, Rio Grande, Animas, Dolores, Colorado, White, and Yampa. Because these rivers can carry out much of the material being eroded from the Front Range, the intermontane basins are not "clogging" with sediment as they did earlier. Instead, erosional stripping in the mountains is helping to **accentuate the relief** between the ranges and the flanking basins.

Volcanic activity diminished during this interval, but some lava flows continued in northwest, southwest, and southeast Colorado. No rock units from this interval are preserved in Boulder.

1.5 mya-Present

Processes

Mountain glaciers formed at high elevations west of Boulder. Valley glaciers extended to within 10 miles or so of town. Downstream from Nederland, the U-shaped portion of the Boulder Creek valley at and above Barker Dam was glaciated, but the V-shaped valley below the dam was not. The last major glacial buildup in Colorado began to recede about 10,000 years ago.

Streams fed by increased glacial meltwater carried eroded sediments out of the Front Range and cut **successively lower terraces** through the deposits that lined the front of the foothills. As river downcutting continued, higher gravelled surfaces were left stranded and formed **mesas** such as Rocky Flats, the NCAR mesa, and Enchanted Mesa. Erosion by the South Platte River and its tributaries formed the Colorado Piedmont along the eastern flank of the Front Range. In the last 250,000 years, windblown sand and silt from older alluvial surfaces has blown eastward across the plains to form dune and loess deposits.

Soils have developed on top of many of the alluvial and windblown deposits of these intervals.

To the west of our area, isolated **lava flows** continued until quite recently. The latest lava flow at Dotsero, east of Glenwood Canyon, Colorado, occurred about **4,000 years ago**.

Erosion is the dominant force altering the Boulder landscape today. In most of Boulder County, the rocks directly below the soil and modern-day sediments are at least 65 million years old, and some are 1.7 billion years old. If the sediments from the last 1.5 million years are someday buried and lithified to form rock units, an unconformity of more than 65 million years - and more than 1.7 billion years in some places - will lie between the older rocks and the newly formed rock units. The unconformity we are "working on" now will someday be represented in the rock record as a gap in time that in some places is even longer in duration than the unconformity we now see between the Precambrian rocks and the Fountain Formation.

Names and Exposures

The **alluvium left by rivers** draining the mountains has not been lithified into rock units, but several terraced levels representing discrete intervals of deposition and erosion have been given names.

The Rocky Flats Alluvium was deposited 1 to 2 million years ago in an alluvial fan system best seen in the nearly flat surface that slopes gently eastward from the mouth of Coal Creek Canyon. Over time, streams in our area have cut downward so that this old alluvial surface is now 300-350 feet above current stream levels.

The Verdos Alluvium was deposited around 600,000 years ago along stream surfaces cut down into the older alluvium and bedrock. It lies as much as 250 feet above current stream levels and is best seen on the nearly flat surfaces near CU and Fourmile Canyon.

The Slocum Alluvium developed about 150,000 to 260,000 years ago. It lies as much as 130 feet above current stream levels. It appears to be cut locally by the Valmont Fault, which would indicate that an episode of faulting occurred more recently than deposition of the alluvium.

The alluvium deposited in the Rocky Flats, Verdos, and Slocum terraces is associated with the **gravelly covered erosional pediment surface** that cuts a very gently sloping, very low-relief profile across the bedrock in the transitional zone between the foothills and the plains. The rock layers below the thin gravelly cover on the terraces and mesas are tilted steeply like the exposed layers that are visible in the foothills - it is only the erosional surface that cuts across them and the gravelly cover that has been laid down on top that are nearly horizontal.

Within this area, additional episodes of cutting and deposition have laid down sands and gravels in drainages within the broad Boulder Valley. The Louviers Alluvium was deposited about 140,000 years ago and now lies as much as 65 feet above current stream level. The Broadway Alluvium was deposited about 30,000 years ago and now lies as much as 40 feet above stream level; alluvium of this age is present between Boulder Creek and South Boulder Creek and is also the ground surface that the city of Denver is built upon.

"Modern" sediments of the Piney Creek Alluvium were deposited along stream valleys in the area about 2800 years ago and also produce commercial sand and gravel from surfaces as much as 20 feet above current stream level. "Post-Piney Creek Alluvium" deposited about 1,500 years old along the current floodplains of streams is up to twenty feet thick.

Some of the older alluvial units as well as most of the younger ones are quarried for **gravel, sand,** and **clay**.