Geology Tour
Of The
Upper Arkansas River Rift Valley

Geology Narrative V1.1

Crystal Lakes/Hayden Meadows

- The wide valley in which we are located is a portion of the Rio Grande Rift valley running from southern Wyoming in the north to Mexico to the south, the part of a rift structure that drops (called a graben) between the uplifted and tilted rims (called horsts) that rise as walls along a rift valley due to the tensional tectonic forces spreading (or pulling) a rift apart, exposing rocks lower in the rift walls from deep within the earth's crust. From the valley here through most of the valley south to Poncha Springs, it is thought by geologists that the rim height of the horsts to valley floor depth of the graben after rift formation may have been on the order of twenty to twenty-five thousand feet. The graben, or rift valley, has since been filled up to fifteen thousand feet with sediments from glacial activity, weathering, and catastrophic events such as floods. The mountain heights have also been eroded, leaving now a depth of up to around seven to eight thousand feet.
- To the east and west, the rift horsts have created mountain ranges exposing a significant amount of regionally metamorphosed basement rock (mostly banded and folded gneiss) along with un-metamorphosed basement granitics, mostly granodiorite, and granite intrusions. The west rift horst is the Sawatch Range and the east rift horst is the Mosquito Range. Notice the significant glaciation that has occurred to both mountain ranges here and to the north.
- To the north, the rift, valley and rims, turns northeast to Fremont Pass, then north through Blue River and Ten Mile Canyons from Fremont Pass to Silverthorne (the split caused by severe spreading and faulting due to the rifting), Middle Park and Kremmling with another possible spreading split to Muddy Pass and on through Steamboat Springs to very southern Wyoming on the west and through Granby and North Park to Wyoming on the east.
- Looking to the south, the east and west rift horst walls seem to be coming together and, in fact, the east and west margins of the rift drift close together to form Granite Canyon before spreading apart again to the south in the Buena Vista to Salida region to form another wide rift valley. This spreading and squeezing pattern is repeated a number of times along the north/south path of the Rio Grande Rift. Continuing to the south, the rift runs through Poncha Pass and the San Luis Valley, then south through New Mexico along the Rio Grande Valley well into Mexico.

Twin Lakes

- Near the east end of the Lake Creek drainage, we have the Upper and Lower Twin Lakes. These are glacial lakes formed by the Lake Creek Glacier in the last glacial period. Originally, they were separate lakes, with the upper lake being higher in elevation than the lower lake. A prominent end moraine for the upper lake is still visible at its east end. Looking north from the east end of the lower lake, the north lateral moraine of the Lake Creek Glacier is clearly visible. Looking east, the remains of the end moraine of the lower lake are visible. And, looking west along the

south side of the lake, the south lateral moraine of the glacier can clearly be seen. At the Lakeview Campground Overlook, you are on top of the north lateral moraine of the Lake Creek Glacier and you can examine both glacial till and glacial outwash. Looking south over the Twin Lakes, the end moraine of the upper lake is clearly visible separating the two lakes and the south lateral moraine is visible on the south side of the lakes.

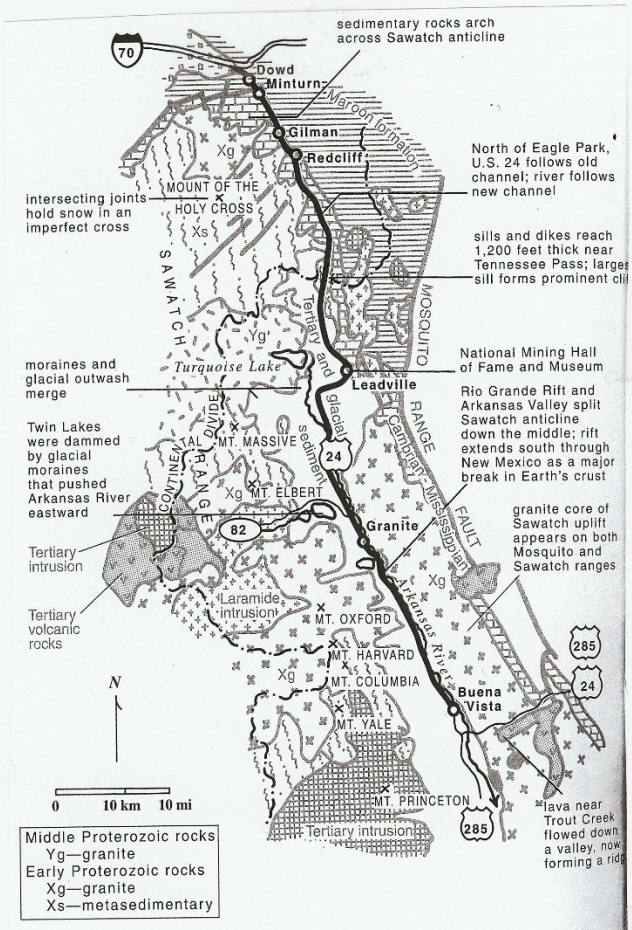
- On the drive up the valley from US 24 to the lower lake, many large boulders are noticeable on both sides of the highway scattered around. These are glacial erratics plucked off the canyon walls and floor upstream and dropped as the glacier receded.
- Looking west up the Lake Creek valley, the prominent U-shape of the valley is visible, showing the distinct shape cut by glaciation. The depth of this valley is typical of the valleys cut by glaciation in the Sawatch and upper Mosquito ranges. Glacial ice is thought to have accumulated to up to, and even beyond, 2000 feet in depth at the height of the last glacial period, cutting these magnificent forms.
- The high point of the west horst, as represented by spine the Sawatch Range, is visible close to the west of the lakes as represented by the 14000 foot peaks visible from the lower lake – Mt. Elbert, Mt. Massive, and Mt. Oxford. The continental divide, on the westward downslope of the horst on the west side of the Rio Grande Rift, is far west up the Lake Creek drainage - not visible from the lakes. Many thousands of feet of basement crust have been uplifted here as seen westward from the lower lake, with a great deal of basement metamorphosed and lower crustal granitic rock from far down in the earth's crust being revealed.

Granite

- To the north through Balltown, the Arkansas River, primarily following near the fault line of the Rio Grande Rift where the east and west margins are beginning to pinch more together, has worked its way through a shallow canyon with the Precambrian basement granitics visible on both sides of the river. The uplift of the rifting raised these basement rocks to the surface in this area and formed a course for the river. Where the Lake Creek drainage at Balltown enters the canyon from the west, a great deal of glacial stratified drift and remains of placer mining are piled around the basement granitics, pushing the river to the east side of the graben.
- To the south, just below the town of Granite, one or more ice dams formed during the glacial receding period and burst to create at least one or two enormous catastrophic flood scouring out the deeper Granite Canyon, which is now the Arkansas riverbed, in the Precambrian basement granitics. South from here to the Pine Creek drainage area, this canyon of granitics exposed by the tectonic-caused uplift of the east and west horsts of the rift, where the east and west margins of the rift have squeezed together, continues and forms the course for the river.

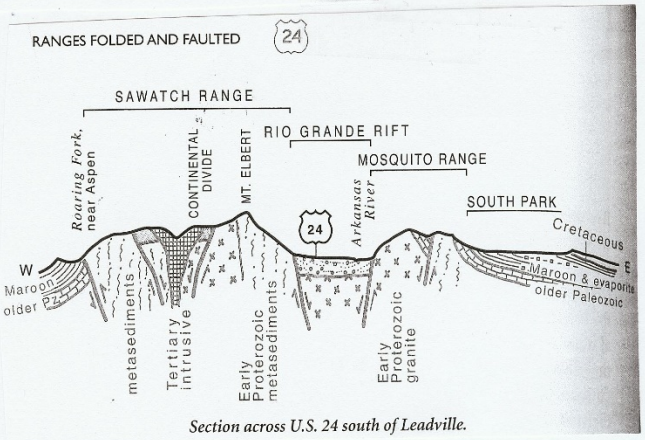
Clear Creek

- To the south, in this region where the east and west horsts of the Rio Grande Rift squeeze more closely together, we see Granite Canyon cut along the east margin of the rift. The rift valley is scoured out and quite deep and narrow here and possibly the depth was enhanced by the violent flood activity from the breeching of one or more ice dams that evidence shows formed just south of the town of Granite during the retreat of glaciation in this region. Along the west



Geology along U.S. 24 between Buena Vista and I-70.

1. Halka Chronic and Felicie Williams 2002. Roadside Geology of Colorado. Second Edition. Missoula, Montana: Mountain Press Publishing Company, 142
2. Halka Chronic and Felicie Williams 2002. Roadside Geology of Colorado. Second Edition. Missoula, Montana: Mountain Press Publishing Company, 144



Section across U.S. 24 south of Leadville.

wall of the rift at Pine Creek, banks of glacial till are visible – the remains of the Pine Creek and Clear Creek Glaciers flowing into and across the rift valley, glaciers thought to have contributed to the ice damming on the Arkansas.

- To the north, we see the Arkansas River flowing out of the upper Granite Canyon, the deep and narrow rift valley possibly deepened by the ice dam breeches, thought to have been caused by the glacier flowing out and across the rift valley from Clear Creek Valley and combining with the Pine Creek Glacier to the south to contribute to the ice dam on the river.
- The walls of the canyons here (on both the east and west sides) are primarily the beautiful Precambrian basement tan granitics exposed by the tectonic-caused uplifts of the east and west horsts of the rift. This canyon of granitics (where the east and west margins of the rift have squeezed together) continues north through the towns of Granite and Balltown to just south of the Kobe RR siding, where the rift valley spreads out and opens up. Where drainages enter the canyon from the west (Pine Creek, Clear Creek, and Lake Creek), banks of glacial till and stratified drift (sorted glacial materials) can be seen along with remains of placer mining.

The Numbers

- The east and west horsts of the Rio Grande Rift converge closer just north of here and squeeze together from this point north of to just below the Kobe RR siding. Just to the north, we see the mouth of Granite Canyon. Here, the Arkansas River has acted to scour out the deep and narrow valley created by rifting and making the course for the river. Canyon cutting activity may have been enhanced during the retreat of the glaciation in this region by the breakage of one or more ice dams that some evidence shows may have formed just south of the town of Granite, with powerful catastrophic flooding as a result.
- To the east, in spots here the top of the east horst of the Rio Grande Rift can be seen with the volcanic slopes of Buffalo Peaks sitting on top. The volcanic activity here is thought to be some of the oldest of the region. Up to the volcanic cap, this east horst of the rift, due to its uplift, has exposed the beautiful Precambrian basement tan granitics.
- To the north of The Numbers, it is noticeable that glacial activity on both the west and east rift horsts has been very pronounced. From here to the south to Salida and Poncha Springs, the glacial activity was primarily confined to the west horst.

Railroad Bridge

- Along this section of the east margin of the Rio Grande Rift (from Salida in the south to The Numbers in the north), the Arkansas River has been forced tightly against the east margin by massive glacial outwash and alluvial fans from the east side of the Sawatch Range. In this area, the Arkansas River has cut a small canyon on the edge of the sedimentary deposits in the rift valley at the east rift margin. But, the valley itself was not cut by the river but created due to the rift uplift and spreading.
- To the east all along this region, the basement Precambrian tan granitics have been exposed at the surface by the uplift of the east horst of the rift and glacial outwash has been exposed on the banks of the river, especially on the west side. From this point on south ward, we begin to see some banded gneiss appearing lower walls of the east horst. The west horst here is made up of granitics, primarily granodiorite, and banded and folded gneiss

Collegiate Peaks Overlook

- To the northeast, east, and southeast, the basement Precambrian granitics, including granodiorite and monzonite, are visible as they extend up and down the east horst of the Rio Grande Rift. Occasionally, some basement metamorphosed rocks (banded and folded gneiss) are encountered.
- Far to the east, the top of the east rim of the rift (east horst) is visible. In this region, the top of the rim is still capped with some of the lowest sedimentary layers deposited in this region – Cambrian, Ordovician, Mississippian limestones, sandstones, and shales. The cliffs visible to the east-north-east on the top of Limestone Ridge and Kaufman Ridge farther southeast are primarily Ordovician Manitou, Harding, Fremont, and Mississippian Leadville Limestone.
- Closer to the east-south-east, the ridge (Triad Ridge) running east/west, paralleling the highway east toward Trout Creek Pass, is capped is with a gray volcanic tuff that may have been deposited as a result of the volcanic activity here along the margins of the Rio Grande Rift, including the Wall Mountain Tuff layer at the top possibly from the Aetna Volcanic complex.
- To the west, the west horst of the Rio Grande Rift rises grandly as the Collegiate Peaks section of the Sawatch Range with many fourteen thousand foot peaks in this stretch (Mt. Shavano, Mt. Antero, Mt. Princeton, Mt. Yale, Mt. Columbia and Mt. Harvard south to north). The rocks of the Collegiate Peaks section of the west horst of the rift are primarily Precambrian granite/syenite/granodiorite with progressively more metamorphic banded and folded gneiss as you move northward. Along the west margin of the rift at the base of these peaks, the rift spreading has allowed hydrothermal activity to rise to the surface as hot springs, the major ones at Poncha Springs, Mt. Princeton, and Cottonwood Creek.
- As can be seen looking to the east, the Mosquito Range (south of Buffalo Peaks, often called the Arkansas Hills) does not rise as grandly as does the Sawatch (west horst) to the west of us. This is due to a series of faults parallel to the rift (north to south directed) that developed on the east side of the rift from the Buffalo Peaks area south to the Salida area. So, the east horst rises in a series of eastward rising steps all the way from here south to Salida to its top to the east - Kaufman Ridge.

Ruby/Sugarloaf Mountains

- On the east side of the river, we see Ruby Mountain, a large grayish white volcanic outcrop consisting primarily of rhyolites, with some andesite, pumice, and vitrophyre flow materials (loaded with Apache Tears). Just to the north and west, we have Sugarloaf Mountain, a large reddish tan hill that consists almost entirely of rhyolite, another volcanic outcrop along the east margin of the Rio Grande Rift in this location, the Nathrop Volcano Field. Some or all of this may have come from Bald Mountain, a volcanic cone that sits just to the northeast of this National Monument location, along the primitive continuation of County Route 300, and/or from a volcanic vent between Ruby and Sugarloaf mountains or a vent at the north end of Sugarloaf – now covered by talus debris generated more recently.
- To the east of the National Monument Recreation Area, the base of the east horst of the rift with the characteristically tan Precambrian basement granitics, mostly

granodiorite, can clearly be seen. These granitics are exposed all along the base of the east rift horst in this region to the north and south, with their younger sediment cap laid on top of them far above and to the east.

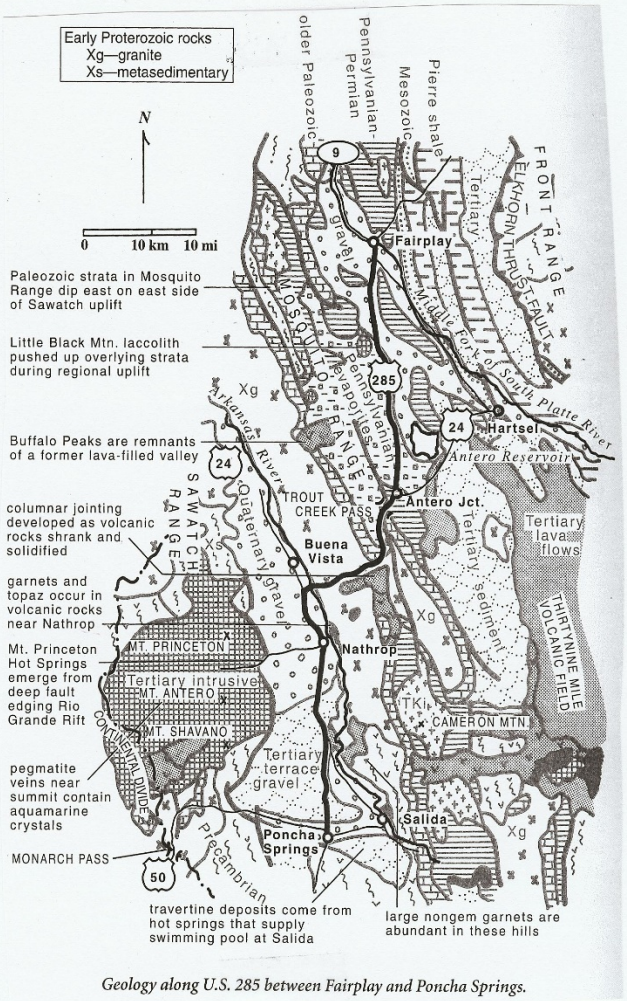
- To the northeast, visible from the road into this National Monument site on the northwest corner of Sugarloaf Mountain, the high mountains of the east horst of the rift can be seen. This is the southern end of the main section of the Mosquito Range and the specific mountain visible is Buffalo Peaks, the remains of a volcanic deposit that sits on top of the east horst.

Chalk Cliffs Pullouts

- To the west across the rift valley, the Sawatch Mountain Range rises as the west horst of the Rio Grande Rift. The rocks of this mountain range are primarily Precambrian basement granitics with some metamorphosed rock (banded and folded gneiss). At the base of this mountain range, along the west margin of the rift, runs the active west horst fault that facilitates hot spring activity from Cottonwood Creek on the north to Poncha Springs on the south. From the base of the east end of the Chalk Cliffs, the west horst fault takes an unusual sharp turn to the west and proceeds west up Chalk Creek for two miles, where it again takes a sharp turn to the south and proceeds southward. From the Colorado Trail turnout at the faults western bend, fault damage can be viewed through the south lateral moraine of the Chalk Creek Glacier and the east ridge of Mt. Antero to the south. Notice also the very light to white granitic material and white kaolinite clay visible from Cottonwood Creek on to the south – especially in Chalk Creek and around the Colorado Trail turnout. The springs are a result of hydrothermal flow from deep within the earth, allowed to escape to the surface due to the spreading margin of the rift's west horst and the unusual bend in the fault here.
- These white cliffs, visible on the west side of the valley at the southeast base of Mt. Princeton (and to a lesser degree at the mouth of Cottonwood Creek to the west-northwest of Buena Vista), of Syenite and Kaolinite are the result of a chemical metamorphism caused by hydrothermal flow contact with granite's feldspar at and near the surface of the earth in this area and the included white Kaolinite is the result of accelerated decomposition of the white plagioclase feldspars in the Syenite granite into a white clay, exposed now at and above the surface by the rift uplifting.
- The valley floor west of the Arkansas River here is covered with glacial gravels. Rimming the north and south sides of the Chalk Creek valley as it proceeds east across the rift graben floor from between Mt. Princeton and Mt. Antero to the Arkansas River (that lies on the east side of the rift valley here) are two low ridges, possibly lateral moraines, that consist of glacial till mixed with glacial outwash that were manufactured as the glacier cut out the valley and left deposited on the sides and floor of the valley after the glacier receded back into the Chalk Creek drainage.

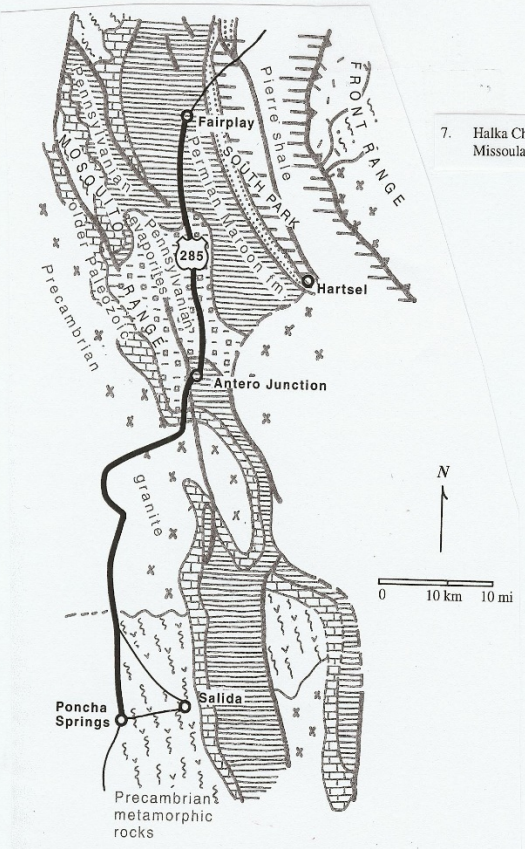
Hecla Junction

- To the east and northeast from the beach at the river, the east horst of the Rio Grande Rift is in front of you with the beautiful tan Precambrian basement granitics visible. The characteristic tan coloring of these granites is what gave rise to the canyon of the Arkansas River in this area being named Brown's Canyon.
- On the east bank of the river some Precambrian basement metamorphic rock (banded and folded gneiss) is visible with its characteristic dark coloration and banding. The metamorphosing of these basement rocks was caused most likely by the intense



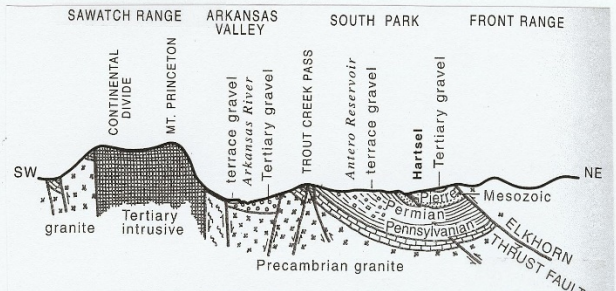
Geology along U.S. 285 between Fairplay and Poncha Springs.

6. Halka Chronic and Felicie Williams 2002. Roadside Geology of Colorado, Second Edition. Missoula, Montana: Mountain Press Publishing Company, 196



The geologic map of this area (opposite) *looks hopelessly complex. But if we omit Tertiary and Quaternary deposits* (this page), *a simpler pattern emerges: north-south bands of Paleozoic and Mesozoic strata caught between two uplifted blocks of Precambrian rocks. The youngest Paleozoic strata are on the east side of South Park and the oldest are on the west because this is the eastern limb of a large faulted anticline.*

7. Halka Chronic and Felicie Williams 2002. Roadside Geology of Colorado, Second Edition. Missoula, Montana: Mountain Press Publishing Company, 197



Section across South Park and the Sawatch Range at Trout Creek Pass.

8. Halka Chronic and Felicie Williams 2002. Roadside Geology of Colorado, Second Edition. Missoula, Montana: Mountain Press Publishing Company, 198

pressures and heating of the tectonic activities of the crustal rifting and the large blocks of crust rotating, uplifting, and stretching.

- Just to the west of the beach area, the road drops through an area of dark gray low cliffs – a dacite ash flow from the volcanic activity along the east margin of the Rio Grande Rift in this area.
- A bit farther to the west and extending out to the main highway, you drive through a large deposit of volcanic rhyolite and conglomerate (pink to red to white in color). This is another large deposit of volcanics possibly from the Nathrop Volcano Field or from the farther southwest Aetna or Bonanza volcanic complexes.
- From the top of the hill along the road into Hecla Junction, the beautiful Sawatch Mountains rise to the west across the rift valley, forming the west horst of the Rio Grande Rift. The rocks are Precambrian granitics (syenites, monzonites, and granodiorites) with some metamorphic gneiss mixed in.

Stone Bridge

- To the east, we see primarily rhyolite cliffs and mounds on both the north and south sides of the Arkansas River as it twists here. This volcanic material lies along the east margin of the Rio Grande Rift at the base of the east horst. Its introduction is associated with other volcanic activity along this east rift margin thought to be from the farther southwest Aetna or Bonanza volcanic complexes.
- Notice that these volcanic mounds are surrounded to the east, especially, by basement granitics with their characteristic tan coloring in this area. Their presence is due to the uplift of the east horst of the rift, exposing the Precambrian basement rocks, lifting their younger sedimentary cover high above and quite far back to the east.
- Notice the rounded mounds forming the east margin of the rift valley from here to Salida. Much of the material making up these mounds is rhyolite and thought to be from the Aetna, Grizzly, or Bonanza Volcanic Complexes.

Big Bend

- Of special note at this location, to the south and west we see large alluvial fan deposits from the base of the west horst of the Rio Grande Rift (the Sawatch Mountains) east to the Arkansas River. The tan cliffs (called the Dry Union Formation) just to the south are results of the Arkansas River eroding into the alluvial fan deposits that extend all the way to the river at this point from Mt. Shavano.
- The rift valley west of the Arkansas River from the Mesa Antero subdivision to the north down to this point did not have glaciers come out this far from the Sawatch (they were thought to not flow below about 8000 feet in elevation in Colorado) but the alluvial fan deposits in this area east of the Sawatch contain the products of the glacial activities in the Sawatch Mountains to the west that were washed out and deposited by streams. Since this glacial material, known as glacial outwash, was carried and deposited by water instead of the glaciers themselves, the material is more sorted and layered (stratified) and more rounded than angular.
- Alluvial fans are generated by stream flow that is abruptly slowed as here by the flattening of the terrain east of the west horst of the rift. Streams no longer have the energy to carry the materials they had been able to carry steeply downhill so the larger heavier materials drops out (or settle to the ground) first as the water flow slows, followed by smaller and smaller materials as the water progresses eastward.

The water fans out into a fan-like structure as it encounters flatter terrain, thus leaving large fan-shaped deposits of glacially milled materials.

- Judging by the size and extent of the deposits, the streams had many violent and large flows in the past as the glaciers melted and receded back high up into the mountains.
- To the east across the relatively flat plain of the rift valley (graben) we see the east horst of the Rio Grande Rift. Notice that there are no alluvial fans visible emanating from the drainages of the east horst of the rift in this lower rift valley. That is because there was no significant glaciation along the mountains of the east horst uplift until north of Buffalo Peaks (well north of Buena Vista), the large three-lobed mountain that can be seen to the northeast on top of the east horst of the rift.

Poncha Springs

- To the south, the Rio Grande Rift continues south over Poncha Pass, through the San Luis valley into New Mexico where it captures the Rio Grande River, and on south into Mexico. There is some evidence that volcanic activity and crustal shifting along the margins of the rift may have been the cause of diverting the flow of the Arkansas River from southerly, as some evidence may suggest it once did, into the San Luis valley to southeasterly into Upper Big Horn Sheep Canyon at Salida. There is evidence interpreted by others to say that the Arkansas never flowed through Poncha Pass.
- The west horst can be seen west of Poncha Springs rising to Monarch Pass with 14'ers Mt. Shavano and Tabeguache Mountain. Here, the horst consists primarily of Precambrian basement granitics with more basement metamorphic gneiss and schist as you proceed north along the west horst of the rift.
- The valley to the west was carved by the Monarch glacier and a great deal of glacial-manufacture till and outwash is deposited in this area – up to 15000 feet deep on the west side of the graben here. See the Salida section for a further discussion of fill in the graben in this area of the rift.
- To the southeast, the Sangre de Cristo Mountain range, the south continuing east horst of the rift, can be seen swinging northwestward to form the east side of Poncha Pass. This is an unusual twist and extension of the east horst that also starts straight north from east of Salida. This Methodist Mountain complex that is the horst's very northwest end is made of the same late intrusion of granitic magma that formed the Princeton batholith and Big Baldy Mountain complex.
- Just to the north of Poncha Springs there is a very long and pronounced planation surface extending from the north side of the Monarch Pass drainage at the foot of Mt. Shavano to Salida – again Dry Union Formation made of glacial outwash.

Salida

- Salida is a major junction point of different geologic zones in the earth's crust. To the north and south, we have major tectonic tensional activity that caused the creation of the Rio Grande Rift represented here by the San Luis and Upper Arkansas River valleys (along with others both to the north and south) forming the rift valley. Salida lies at the east margin of the rift valley while Poncha Springs lies closer to the west margin and the Sawatch Mountains west of Poncha Springs (that form the west horst of the rift) while the Mosquito Mountains/Arkansas Hills form the east horst of the rift just to the east and north of Salida. To the southeast of Salida, Hwy. 50 turns east,

leaving the rift valley, and follows faults through the east horst of the rift, a very different geology than that of the rift valley and tops of the horsts surrounding the rift.

- To the southeast, the Arkansas River leaves the Rio Grande Rift valley and enters Upper Big Horn Sheep Canyon – a canyon formed by a great deal of faulting in the earth's crust by the tensional rifting and uplifting of the rift's horst. The canyon faulting goes all the way toward Coaldale through which you travel down in elevation but up in geologic time from the basement Precambrian rocks exposed by the east horst uplift at Salida up through successively younger layers of Paleozoic sedimentary rock as the east horst of the rift slopes downward to the east toward Coaldale.
- To the west of Salida, we have a large opening up of the Rio Grande Rift valley (graben), significant spreading of the earth's crust, which runs primarily north/south from very southern Wyoming north of Steamboat Springs and North Park to well into Mexico to the south. Unlike the rift grabens to the north of Granite and south of Poncha Pass, the bottom of the graben here is severely sloped down from east to west. A graben sloped like this is called a half-graben or hinged-graben and it is caused here by the series of north/south running faults parallel to the rift on its east side from Salida to the Buffalo Peaks area. The depth of fill on top of this slanted bottom goes from approximately 3000 feet on the Salida side to 15000 feet on the Poncha Springs side and these depths are consistent to where the rift pinches together north of Buena Vista.
- To the immediate east of Salida, a lava flow covers the basement Precambrian rocks (granodiorite, diorite, gabbro, Proterozoic metasediments and volcanics, and metamorphics) along the east margin of the rift south to near Upper Big Horn Sheep Canyon. This large array of ancient rocks becomes visible just to the east of the lava flow in the gulches east of Salida and in the mouth of the Upper Big Horn Sheep Canyon where soon to the east of Salida the dramatic dip of the east horst exposes some of the sandstone and green to maroon shales of the middle Cambrian, the Ordovician Manitou Limestone/Harding Quartzite/Fremont Dolomite, Devonian Parting Shale/Dyer Dolomite, and Mississippian Leadville Limestone.
- To the north, the Arkansas River follows the Rio Grande Rift to its headwaters at Fremont Pass northeast of Leadville. It is the rifting that created the path for the river. Along the east margin of the rift and localized to that margin (except for the Aetna Volcanic Complex just northeast of Monarch Pass), there is much evidence of volcanic activity north to the Buena Vista area just as you can see here in Salida (the Salida Volcano Field made up of Tenderfoot, the Crater, Big Baldy, and Waugh Mountains). Along the east horst, much of the Precambrian basement rock exposed is granodiorite, diorite, gabbro, and banded/folded gneiss.

Arkansas Headwaters Recreation Area

Glossary of Geological Terms for the Upper Arkansas Valley (V3.1)

- Accretion (Continental): a large wedge-shaped mass of sediment scraped from the subducting plate and added to the end of the overriding crust.
- Agate: a form of chalcedony in which adjacent bands differ in color and degree of translucency.
- Alluvial: a fan-shaped deposit of unconsolidated sediment deposited by a stream when the slope of the fall of the stream suddenly begins to flatten.
- Andesite: Volcanic extrusive igneous rock having a makeup between that of granitic (felsic) and basaltic ferromagnesian (mafic) rocks.
- Aphanitic Texture: a texture of igneous rocks in which (many or most of) the crystals are too small for individual minerals to be distinguished with the unaided eye.
- Basalt: an extrusive igneous rock made up of fine crystals containing abundant dark, dense ferromagnesian minerals and low in silica, the volcanic equivalent of gabbro.
- Batholith: a large mass of intrusive igneous rock that formed when magma was emplaced at depth in the crust, crystallized, and was subsequently exposed.
- Bedding Plane: a nearly flat surface separating two beds of sedimentary rock, each plane marking the end of one deposit and the beginning of another having different characteristics.
- Biochemical (Organic) Sedimentary Rock: chemical sediment that forms when material dissolved in water is precipitated by water-dwelling organisms (shells and skeletons).
- Biotite (Mica): a form of the potassium aluminum silicate mica group with the addition of iron and magnesium to its chemical composition, making it blackish in color.
- Breccia: a conglomerate sedimentary rock composed of angular (not smoothed) fragments included in a matrix.
- Chalcedony: the formation of chert nodules and lenticles (lenses) by partial replacement of limestone with microcrystalline quartz (silica). Often occurs with iron and/or aluminum.
- Chemical Sedimentary Rock: sedimentary rock consisting of mineral material precipitated from water by organic or inorganic means. See **Sedimentary Rock**.
- Chemical Weathering: the process by which the internal structure of a mineral is changed by the addition and/or removal of elements.
- Chert: rock formed by precipitation of microscopic **microcrystalline quartz** crystals from solution or microscopic skeletons (whole or broken) of certain algae, planktons, and protozoans.
- Clasts: broken fragments of preexisting rock.
- Cleavage: the tendency of a mineral to break along planes of weak chemical bonding.
- Colluvial: compacted rock and soil accumulated on a relatively flat area at the foot of a slope.
- Conchoidal Fracturing: a glass-like fracture having the shape of the inside surface of a bivalve shell.

- Conglomerate: a sedimentary rock consisting of two types: rounded, gravel-sized inclusions called just conglomerate or angular inclusions called **breccia**.
- Cross-bedding: sedimentary rock in which layers are inclined at an angle to the main bedding.
- Crystallization: the formation and growth of a crystalline solid from magma.
- Dacite: an extrusive igneous rock that is the volcanic equivalent of granodiorite.
- Density: the weight per unit volume of a particular material (mineral).
- Detrital Sedimentary Rock: rocks that form from materials that originate and are transported as solid particles derived from chemical and mechanical weathering. See **Sedimentary Rock**.
- Dike: a tabular-shaped intrusive igneous feature that cuts more vertically through surrounding rock.
- Diorite: an intrusive igneous rock where the mineral content is a mixture of less dense felsic minerals and the more dense ferromagnesian minerals increasing to around 50%.
- Dip: the angle of inclination of a rock layer measured from the horizontal.
- Dolomite Rock: essentially the same structure as limestone, this rock is composed primarily of **dolomite** – the mineral calcium magnesium carbonate. It is denser than limestone and, thus, weathers over a longer period due to lower solubility and develops curved faces and rough surfaces and has a more pearly luster.
- End or Terminal Moraine: a ridge of **glacial till** that forms at the terminus of a glacier.
- Extrusive Igneous Rock: igneous rock from magma that cooled very quickly as it rose from the earth to the Earth's surface or into water (also called **Volcanic Rock**).
- Fault: a crack or break in the Earth's crust along which movement is taking place or has taken place in the past.
- Feldspar: See Orthoclase Feldspar Group and Plagioclase Feldspar Group.
- Felsic Silicate Minerals: a term derived from feldspar and silica (quartz) used to describe granitic igneous rock – the igneous rock high in light metal silicate minerals (sodium, potassium, aluminum, silicon).
- Ferromagnesian Silicate Minerals: silicate minerals containing iron and/or magnesium as part of their molecular structure as well as minerals of manganese and calcium, causing a darker color and higher density than non-ferromagnesian minerals.
- Fining Upward: sequences of layers of sedimentary rock where the particles of each adjacent layer making up a sequence become increasingly finer up through each layer in the sequence.
- Fissure: a crack in the earth along which there is distinct separation but no movement.
- Flint: a form of chalcedony or chert.
- Flood Basalts: flows of basaltic lava issuing from cracks or fissures and commonly covering extensive areas to hundreds of meters of thickness.
- Folding: bent layer(s) of rock that were laid down horizontal but were later deformed.
- Foliation: a linear arrangement of textural features of metamorphic rock (gneiss) giving the rock a layered appearance.
- Fracture: the breakage of a mineral where there are no planes of weakness in the crystalline structure (i.e. conchoidal, irregular, splintery).
- Gabbro: the intrusive equivalent of basalt, very dark green to black in color and composed primarily of the heavy-metal (iron, magnesium, manganese, and calcium) dense minerals hornblende, olivine, pyroxene, and calcium feldspar.

- Glacial drift: all sediments of glacial origin no matter how they were deposited.
- Glacial stratified drift: materials deposited by glacial melt water and, thus, sorted according to the size and weight of the material.
- Glacial till: materials deposited directly by glacial ice and, thus, usually unsorted and unstratified mixtures of glacially-carved out material.
- Glass (volcanic): produced when molten magma cools too rapidly to permit crystallization – composed of unordered atoms and no crystals.
- Gneiss: metamorphic rock where dark and light silicate materials have separated into distinct bands that may have even been twisted (**Folded Gneiss**) by high degrees of pressure and temperature.
- Graben: a valley formed by the downward displacement of a fault-bounded block of earth's crust (see **Rift**).
- Granite: igneous rock composed mostly of the light-metal (aluminum, potassium, sodium, and silicon) and low density silicate mineral crystals of the minerals quartz, feldspars (usually more orthoclase than plagioclase), mica, and hornblende.
- Granitic (Granite Family): granite-like igneous rock composed of light-metal silicate minerals (quartz, feldspars, and micas) and, generally, more (by percentage) heavy-metal denser silicate minerals (from iron, magnesium, manganese, and calcium) than in granite.
- Granodiorite: a granitic rock having the same light-metal minerals as granite but in different proportions: Higher content of the plagioclase feldspars, biotite mica, and hornblende.
- Graywacke: an impure, greenish to blackish gray dirty sandstone composed of quartz and feldspar grains along with rounded to angular fragments of shale, slate, chert, granite, etc.
- Groundmass: matrix of smaller crystals within an igneous rock that has a porphyritic texture.
- Gypsum: a very common sulfate salt mineral of calcium, developing primarily in sedimentary rocks of chemical (evaporate) origin
- Hornblende: a heavy metal igneous iron/magnesium silicate mineral of the amphibole family that is a building block in the formation of igneous rocks.
- Horst: an elongated uplifted block of earth's crust bounded by faults (see **Rift**).
- Hydrothermal Flow: hot watery solution from a mass of magma, especially in the upper magma chambers and above during late stages of crystallization of the magma. This flow may alter crystallizing and crystallized rocks and surrounding rocks (**hydrothermal replacement** of minerals) as well as deposit minerals in surrounding cracks, faults, and fissures of the host rocks of the crust.
- Igneous rock: rock formed by the crystallization of molten magma, either within the Earth's crust or at the surface.
- Inclusion: a piece of one rock unit contained within another.
- Intrusions: magma that has forced its way into cracks, faults, and fissures in previously solidified crustal rock, often found as dikes and sills.
- Intrusive Igneous Rock: igneous rock from magma that cooled, crystallized, and solidified below the surface of the earth.
- Jasper: Chalcedony or chert that is mottled yellow, red, brown, or green.
- Kaolinite: a secondary clay mineral that is formed by the alteration (decomposition) of aluminum silicates (usually feldspars) in soils and rocks (like Syenite) near the surface

- Laccolith: a massive igneous body, more lense-shaped, intruded between preexisting strata.
- Lateral Moraine: a ridge of **glacial till** along the sides of a valley glacier made primarily of debris that fell to the glacier from the valley walls.
- Latite: an extrusive igneous rock that is the volcanic equivalent of the intrusive granitic rock **monzonite** with quartz content of 10% or less and equal percentages of orthoclase/microcline feldspar and plagioclase feldspar.
- Lava: magma that reaches Earth's surface.
- Lava Dome: a bulbous mass associated with a dormant volcano when thick lava is squeezed from the vent, acting as a plug to deflect subsequent gaseous eruptions.
- Lenticular: lense-shaped
- Limestone Rock: a sedimentary rock primarily composed of the mineral calcite (calcium carbonate) formed by either inorganic means or biochemical processes (primarily exoskeletal remains).
- Lithification (lithified): the process generally by cementation or compaction of converting sediments to solid rock.
- Mafic: derived from magnesium, and ferrous and ferric for iron, rocks containing a high percentage of **ferromagnesian** and other heavy metal silicate minerals.
- Magma: a body of molten rock found at depth in the earth (usually from the mantle), including any dissolved gases, rock, and crystals.
- Marble: the rock that results from the metamorphism of limestone and/or dolomite.
- Matrix: material in which larger crystals are embedded
- Mechanical Weathering: the physical disintegration of rock resulting in smaller fragments.
- Medial Moraine: a ridge of glacial till that forms when lateral moraines from two valley glaciers join together.
- Metamorphism: changes in the composition and texture of solidified rock due to high temperature (yet below the melting point of the minerals contained in the rock) and/or pressure after initial solidification or previous metamorphism.
- Metaquartzite: a quartzite formed by the process of metamorphism of quartz sandstones.
- Metasediment: existing sedimentary rock that has subsequently been metamorphosed.
- Mica: a group of potassium aluminum (and iron magnesium) silicate minerals (See **Muscovite Mica** and **Biotite Mica**).
- Microcrystalline Quartz: a form of quartz made up of tiny quartz crystals only visible through a microscope that is often deposited from a hydrothermal flow that is supersaturated with silica in solution.
- Migmatitic: a rock showing both igneous and metamorphic rock characteristics where light-colored silicate minerals melt and recrystallize while the dark silicate minerals remain un-melted.
- Mineral: a naturally occurring inorganic crystalline material with a unique chemical structure (chemical equation).
- Monzonite: an intrusive igneous rock that is in the granitic family. See Latite.
- Moraine: layers or ridges of **glacial till**.
- Muscovite: the basic potassium aluminum silicate mica group, usually white or colorless to an aluminum-looking color when thick.
- Orthoclase (a **Feldspar Group**): potassium aluminum silicates sometimes with considerable sodium.

- Orthoquartzite: sandstone where the grains are nearly pure quartz and the cement is pure silica forming a hard crystalline rock.
- Pegmatite: a very course-grained igneous rock (typically granite) commonly found as a dike associated with a large mass of plutonic rock that has smaller crystals. Crystallization in a hydrothermal-rich environment is believed to be responsible for the very large crystals.
- Pegmatitic Texture: a texture of igneous rock in which the interlocking crystals are all larger than one centimeter in diameter.
- Phaneritic Texture: an igneous rock texture in which the crystals are roughly equal in size and large enough that the individual minerals can be identified with the unaided eye.
- Phenocrysts: conspicuously large crystals, in a porphyry, that are embedded in a matrix of finer-grained crystals (the groundmass).
- Phyllite: a type of dense, hard, crystallization metamorphic rock resulting from the continued medium-grade regional metamorphism on slate under compressive stress producing a wavy to crinkly foliation with visible mica flakes in parallel planes and a pronounced silky sheen.
- Plagioclase (a **Feldspar Group**): a series of mixtures of sodium and calcium aluminum silicates.
- Plate Tectonics: a theory that proposes the Earth's outer layer (the Lithosphere) is composed of individual large plates of crust that move about on the mantle layer below and interact in various ways with one another.
- Pluton: a structure that results from the emplacement and crystallization of magma beneath the Earth's surface.
- Porphyritic Texture: an igneous rock texture characterized by two distinctively different crystal sizes: the larger crystals called **phenocrysts** and the matrix of smaller crystals termed the **groundmass**.
- Porphyry: an igneous rock with a **porphyritic texture**.
- Precambrian or Proterozoic/Archean/Hadean Basement Rocks: all rocks formed before the Paleozoic period when sediments where laid down with the first explosion of fossils of life forms.
- Quartz: the rock consisting purely of the mineral silicon dioxide, one of the family of **silicate** minerals.
- Quartzite: a very hard metamorphic or sedimentary rock formed from quartz sandstone. See **Metaquartzite** and **Orthoquartzite** for the two types of quartzite.
- Pumice: a volcanic rock that forms when large amounts of gas escape through lava to generate a frothy mass.
- Red-beds: refers to a combination of layers of rock in earth's strata that commonly take on a red appearance as a group. See Sangre de Cristo Formation/Maroon Formation/Pennsylvanian-Permian Red Beds in the Geological Rock Layers Section below.
- Rhyolite: an extrusive igneous rock that is the volcanic equivalent of granite, having excess silica.
- Rift: a portion of the Earth's crust where spreading (or separation) is occurring or has occurred and where, in continental crust, elongated blocks of the crust (called **horsts**) parallel to and on both sides of the rift rotate and uplift while the area between the uplifts (called a **graben**) forms a valley by downward displacement along the

uplifting fault-bounded crustal blocks. Continental rifts are thought to be often caused by remote plate tectonic activity below the crust.

- Rock: a consolidated mixture of minerals.
- Rock Cleavage: the tendency of rock to split along parallel closely spaced surfaces (that can be highly inclined to the bedding planes in the rock).
- Sandstone: sedimentary rocks in which sand-sized grains predominate. See **Sedimentary Rock**.
- Schist: a type of metamorphic rock that is course grained with a planar arrangement of platy materials like mica, where the crystals grow many times larger than usual and the quartz and feldspar crystals deform to flat or lens-shaped grains.
- Sediment: unconsolidated particles created by the weathering and erosion of rock, by chemical precipitation from solution in water, or from the secretion of organisms, and transported by water, wind, or glaciers.
- Sedimentary Rock: rock formed from the mechanical and chemical weathered products of preexisting rocks that have been transported, deposited, and lithified.
- Shale: sedimentary rocks in which silt- and clay-sized particles predominate. See **Sedimentary Rock**.
- Silicify: convert into or be injected with silica (often a microcrystalline quartz deposit from hydrothermal flow).
- Siltstones - Mudstone: clay minerals derived from the decomposition (see **Chemical Weathering**) of feldspars with silt-size (microscopic) grains of quartz and flakes of mica. **Shale** is compacted, harder, and thinly laminated while **mudstone** is less compacted, breaks apart more easily and erodes more deeply.
- Silica: the mineral quartz, one of the family of **silicate** minerals.
- Silicate: any of the numerous minerals having the silicon-oxygen tetrahedron as their basic structure (a structure composed of four oxygen atoms surrounding a silicon atom, the basic building block of silicate minerals).
- Sill: a tabular igneous body intruded more horizontally or parallel to the layering of existing rock.
- Slate: a type of dense, hard, microscopic crystalline metamorphic rock of weak luster resulting from a low-grade regional metamorphism of mudstone or shale producing a foliation by alignment of mica flakes in parallel planes along which the rock splits readily into thin sheets.
- Soil: a combination of mineral and organic matter, water, and air – supports plant growth.
- Spalling/Sheeting: the gradual removal of concentric slabs of the outer surface of rock by peeling off in thin fragments/sheets/flakes – an onion skin weathering often due in part on granitics by a great reduction in pressure when overlying rock is removed.
- Specific Gravity: the ratio of the weight of a substance (mineral) to the weight of an equal volume of water.
- Spheroidal Erosion: a weathering process that tends to produce a spherical shape for an initially blocky shape, especially evident in the erosion of granitic rocks.
- Splintery Fracture: when a crystal breaks into splinters or fibers.
- Stock: a pluton similar to but smaller than a batholith.
- Strata: parallel layers of sedimentary rock.
- Strike: the compass direction of a line pointing in the upward direction of the **dip** of a layer of rock.

- Syenite: a granitic rock, like granite but with little quartz, a high concentration of plagioclase feldspar for the feldspar component mostly as late magmatic replacement of potassium feldspar, and may contain some leucite, nepheline, and sodalite (similar to the feldspars but containing less silica).
- Tectonics: large-scale geologic processes that deform the Earth's crust (like Plate Tectonics) through crustal movements.
- Texture: the size, shape, and distribution of the particles that constitute a rock.
- Till: see Glacial Till
- Trachyte: an extrusive igneous rock that is the volcanic equivalent of **Syenite** (granite).
- Tuff: of a dense to fine-grained fragmental texture, tuff is composed of small volcanic rock fragments and ash. **Unconsolidated Tuff**: fragments are weakly solidified by compression and/or cementation (has a rough gritty feel); **Consolidated Tuff**: fragments are moderately compacted into a coherent solidified rock material (usually has a rough gritty feel); **Welded Tuff**: fragments are still so hot when compressed that mineral crystals fuse together as they cool and solidify; and **Flow-Banded Tuff**: fragments of the different minerals separate into like-mineral bands as they flow laterally and settle (primarily found in consolidated and welded tuffs).
- Vesicles: spherical or elongated openings on the outer portions of volcanic rock that were created by escaping gases.
- Viscosity: a measure of the fluid's resistance to flow: the higher the viscosity, the higher the resistance to flow.
- Vitrophyre: see the Tertiary Volcanic Unit in the Geologic Rock Layers Section below.
- Volatiles: gaseous components of magma dissolved in the melt which readily vaporize (form a gas) at surface pressures. Water is by far the most common volatile in magma.
- Volcanic Rock: rock that forms from magma that extrudes from the earth's crust and cools quickly (see **Extrusive Igneous Rock**), resulting in primarily an aphanitic crystal texture.
- Vuggy: small unfilled cavities in rock (especially limestone) where crystals can grow inward from the walls.
- Weathering: the disintegration and decomposition of rock at or near the surface of the Earth. See **Mechanical Weathering** and **Chemical Weathering**.
- Welded Tuff: see **Tuff**.

Geological Rock Layers (Top-To-Bottom Order)
Upper Arkansas Valley

Tertiary Rock/Sand Deposits

Dry Union Formation (Pliocene to Miocene) **–** light gray, yellowish-gray poorly consolidated siltstone, sandstone, conglomerate, and breccia with smaller amounts of interbedded silty and laminated shale

Sangre de Christo Formation/Maroon Formation/Pennsylvanian-Permian Red-beds

Member Three (Lower Permian) – grayish-red and reddish-gray pebbly, granular, course-grained feldspar rich sandstone and orthoquartzite interbedded

with medium and fine-grained feldspar-rich sandstone and conglomerate beds and lesser amounts of mica-rich dark red silty shale beds. There are thin lenticular beds of olive-drab, dark greenish-gray, and grayish-black fine-grained sandstone, siltstone, and shale interbedded with the dominant red-bed sequence

Member Two (Lower Permian and Upper Pennsylvanian) – olive-drab, grayish-green, dark gray, greenish-black, and black mica-like fine-grained shale, siltstone, and rare interbeds of moderate-gray limestone/dolomite/gypsum (at the bottom of the formation) with planar and cross-lamination beds fining upward throughout the formation

Member One (Upper Pennsylvanian) – Grayish-red, dark grayish-red, purplish-red course-grained, pebbly and conglomerate granular feldspar-rich mica-rich siltstone and shale fining upward with cross-beds

Minturn Formation (Middle Pennsylvanian) – gray, olive-drab, grayish-green, greenish-gray, black sandstone, siltstone, shale, and (less commonly) limestone and dolomite

Sharpsdale Formation (Middle Pennsylvanian) – reddish-gray to purple feldspar-rich sandstone and shale with some orthoquartzite

Belden Shale (Lower Pennsylvanian) – dark gray, brownish-gray, and black shale interbedded with thin-bedded medium to dark gray limestone

Kerber Formation (Lower Pennsylvanian) – grayish-green to greenish-brown siltstone, shale and sandstone with rare black shale and gray limestone/dolomite

Lower Mississippian Formation

Chert Member – red, orange, reddish-brown, grayish-yellow vuggy chert

Leadville Limestone – moderate to dark gray limestone with some dolomite

Chaffee Formation (Upper Devonian)

Dyer Dolomite – yellowish-gray to pale yellow with bands of yellowish-gray chert interbedded and lenticular interbeds of light grayish-green and light greenish-gray shale

Parting Quartzite – light-gray, grayish-red, brownish-gray fine-grained conchoidal-fracturing orthoquartzite

Ordovivian Formation

Fremont Dolomite (Upper and Middle Ordovician) – dark, moderate, and light gray fossiliferous dolomite with rare black chert nodules

Harding Sandstone (Middle Ordovician) **–** reddish-gray, grayish-orange, grayish-red and rusty-orange fine to medium grained orthoquartzite where the dense conchoidal-fracturing quartzite is commonly brecciated

Manitou Limestone (Lower Ordovician) **–** dark, moderate, and light gray tan-weathering dolomite and the predominant dark gray limestone content with laminated black and light grayish-white chert lenses occurring parallel to bedding planes

Upper Cambrian Formation

Sawatch Quartzite and Sandstone – light grayish-yellow fine and medium grained silica-cemented sandstone and orthoquartzite

Precambrian Period

Proterozoic

Neoproterozoic

Mesoproterzoic

Paleoproterzoic
Archean
Hadean

Local Rocks of the Precambrian Period

Granite
Interbedded Volcanic and Sedimentary – felsic volcanic, dark basalt flows, fine-grained orthoquartzite, metasiltstone, and metagraywacke
Syenite (Eocene intrusion)
Monzonite (Paloecene intrusion)
Granodiorite (also late Cretaceous/early Paleocene intrusion)
(Quartz) Diorite
Gabbro
Phyllite
Schist
Gneiss

Tertiary Volcanic Unit (occurs mixed in and with the layers above)

Ash Flow-1 Cooling Unit: a multi-ash flow sheet of latite and trachyte welded ash flow tuffs – indications that the flows may have been from the west to northwest.
Antero Formation: andesitic unwelded tuffs and sedimentary tuffs – indications that the flows may have been from the west to northwest.

Dacite – medium to dark gray, greenish-gray on fresh surfaces, light brown, greenish-tan, and light yellowish-brown on weathered surfaces, a tuff (the volcanic equivalent of granodiorite) with visible phenocrysts of sodium feldspar, hornblende, biotite mica, and less common rounded quartz crystals. The groundmass is fine-grained and dark.

Tuff of Badger Creek: six welded rhyolite tuff breccia and andesite ash flows with indications of a close relationship with the Antero Formation.

Wall Mountain Welded Tuff – welded rhyolite ash flow tuff that is light gray, brownish-gray, and grayish-red with prominent phenocrysts of feldspar.
Tallahassee Creek Conglomerate – a boulder conglomerate in a light gray and yellowish-white water laid and air-fall tuffaceous/sand/silt matrix consisting of subangular, subrounded, rounded, and well-rounded clasts of granodiorite, Manitou Limestone, Harding Quartzite, Fremont Dolomite, andesite, Wall Mountain Tuff, and silicified fossil wood fragments (chalcedonic and crystalline silica) that is probably the result of large volcanic mudflows.
Vitrophyre (Nathrop Volcanics) – glassy, light to dark bluish-gray hydrous pyroclastic base of the Nathrop rhyolite flow composed of fine-grained volcanic glass groundmass with phenocrysts (perlite) displaying a "onion-skin" structure and small obsidian nodules.
Rhyolite (Nathrop Volcanics) – light gray, pinkish-gray, and purplish-gray tuff, that is the volcanic equivalent of granite, can be conspicuously flow-

layered and consists of phenocrysts of feldspar and rarely biotite mica in a microcrystalline groundmass. Vesicles sometimes contain well-formed crystals of deep-red spessartine garnet and wine-yellow topaz.

Non-welded Tuff Member (Nathrop Volcanics) – bright white, grayish-white, grayish-orange, grayish-yellow and grayish-red tuff composed primarily of pumice with only very rare volcanic rock fragment inclusions.

Latite of East Badger Creek: flow-banded light gray, lavender-gray, and pinkish-gray latite ash flow following and east-to-west course from Waugh Mountain (found north and northeast of Tenderfoot Hill).

Andesite of Big Baldy: dark-gray, black, and purplish-black fine to medium-grained andesite and basalt breccia and dense, nonvesicular fractured andesite and basalt with the resistant-weathering hilltop exposures forming bodies that are most-likely vertical and near-vertical volcanic plugs rather than remnants of formerly extensive flows. It is thought to be coincident with the Waugh Mountain volcanism.

Ash Flow-7 Cooling Unit: a thick sequence of four trachyte to latite ash flow tuffs of decreasing welding – thought to be in origin from the Thirtynine Mile Volcano Field.

Latite of Waugh Mountain: consists of rhyolite and latite lava flows and flow breccias from Waugh Mountain.

Upper Andesite: – a sequence of andesite and basalt flows, flow breccias, and tuffs. This marks the end of the Waugh Mountain flows.

Tenderfoot Hill Volcanic Sequence: this sequence is thought to represent the last stage of volcanic activity in this area and covers only a small area from the hill. The six basalt and andesite flows are interbedded with sediments that closely resemble the Dry Union Formation.