Geology Tour
Of The
Big Horn Sheep Canyon and Royal Gorge

Geology Narrative V2.0

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 just to the 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 from here and other glacial valleys to the north is deposited in the large rift valley (graben) to our east all the way to Salida – up to 15000 feet deep on the west side of this graben. See the Salida section for a further discussion of graben fill 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. The 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 the 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 to Salida – again Dry Union Formation made of glacial outwash.

Salida

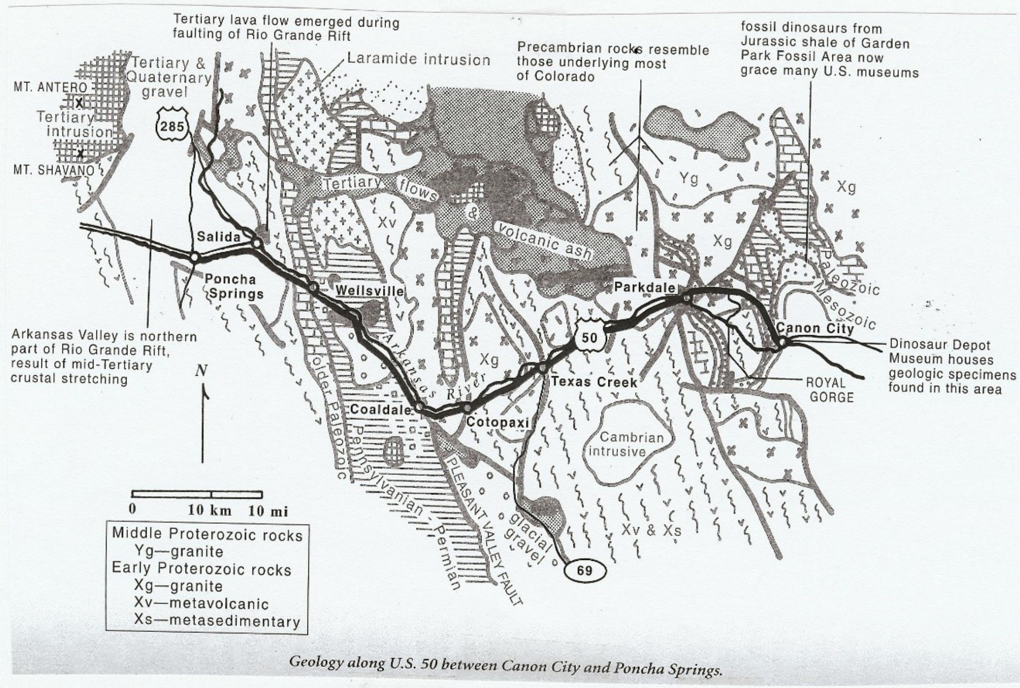
- Salida is a major junction point of different geologic zones in the earth's crust. To the north and south, we have major tectonic tensional activity that caused the creation of the Rio Grande Rift represented by the San Luis and Upper Arkansas River valleys here (along with others both to the north and south) forming the rift valley. Salida lies at the east margin of the rift valley while Poncha Springs lies at the west margin and the Sawatch Mountains west of Poncha Springs 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, leaving the rift valley, and follows a NW/SE trending fault system through the east horst of the rift, a very different geology than that of the graben (rift valley).

- To the southeast, the Arkansas River leaves the Rio Grande Rift valley and enters the Upper Big Horn Sheep Canyon – a canyon formed by a great deal of faulting of the earth's crust by the tensional rifting and uplifting of the rift's east 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 Igneous rocks (the Proterozoic and even some metasediments of the early Proterozoic just southeast of Salida) exposed by the east horst uplift at Salida up through successively younger layers of sedimentary rock (Cambrian/Ordovician/Devonian/Mississippian) to the Pennsylvanian/Permian as the east horst of the rift slopes downward to the east to 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 at least very southern Wyoming north of Steamboat Springs and North Park to well into Mexico in 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 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 (granitics, diorite, gabbro, early 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 lave flow in the gulches east of Salida, including in mouth of the Upper Big Horn Sheep Canyon where soon to the east of Salida the tilt of the east horst exposes some of the tannish sandstones/limestones and gray to yellow to maroon limestones/shales of the middle Cambrian, Ordovician, and Devonian periods.
- 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 (the river did not create this valley). Along the east margin of the rift and localized mostly to that margin, 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 that you see exposed is the beautiful tan granitics (how Brown's Canyon north of here got its name).

Wellsville

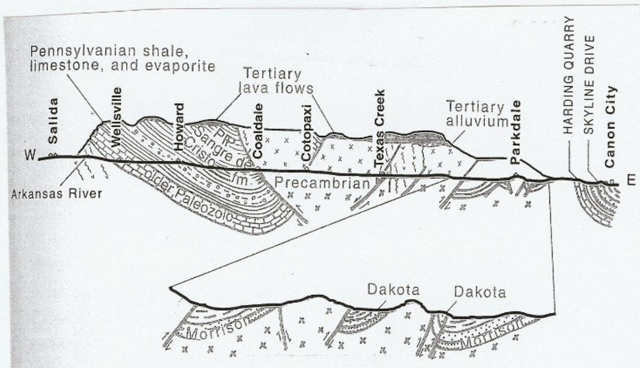
- Deep in Upper Big Horn Sheep Canyon, heavily faulted by the east horst uplift of the Rio Grande Rift, we see, to the east behind the community of Wellsville and to the north and west, Ordovician to Devonian to Mississippian sedimentary rock layers deposited on the top of the Precambrian Basement igneous rocks of the east horst. We have the white/gray (Leadville Limestone) Mississippian layer, brown, white, yellow-to-pink (Dyer Dolomite and Parting Quartzite) Devonian layers, and gray/brown (Manitou, Fremont limestones along reddish Harding sandstones) Ordovician layers.

- To the east and southeast behind Wellsville on the canyon wall, notice the severe faulting and folding of the layers of sedimentary rock. This indicates severe movements of the crust and pressures on the rock after sedimentation, causing the rock layers to warp, crack, fold, and tilt at weird angles. The Wellsville thrust fault (a low-angle reverse fault) has thrust Ordovician Fremont Limestone over the Devonian Parting sandstone layers to the east. This area to the east and southeast is called the Wellsville syncline (rocks in this area have been down-folded), the largest fold in the area. The cave-in feature behind Wellsville is situated over the Wellsville Thrust fault.
- To the northeast and north of Wellsville, across the Arkansas River, the high ridge is known as the Lofgren Anticline. The layers of rock in this area have been up-folded to form the northernmost fold of the area. If you look carefully along the anticline when you are just west of Wellsville, you will see the Wellsville Arch, formed in the Mississippian Leadville Limestone layer atop the anticline. The face of this anticline consists of the complete segment of Paleozoic sedimentary rocks from the lowest middle Cambrian through the Ordovician and Devonian to the Mississippian formation on top.
- Farther west up the canyon above the Precambrian basement rocks uplifted by the rifting, we see the same complete segment of Paleozoic rock formations continuing to rise at a significant angle toward Salida. Proceeding west, you drive down in time through the Devonian, Ordovician, and Cambrian into the Precambrian basement rocks of Earth's crust. When you reach the Fremont/Chaffee county line. You can look across the river and clearly see the junction of the crust below with the sedimentary rock deposited above, known as the Great Unconformity between the Proterozoic rocks of the crust and the Paleozoic rocks of the great sedimentation burying the crust over most of the Earth's continents.
- Proceeding east, you drive up in time through the Devonian, and Mississippian formations to the Pennsylvanian and Permian formations by the time you reach Swissvale. Younger sedimentary layers above the primarily red Pennsylvanian/Permian formation have been eroded away and replaced in some areas here by a dark volcanic cap of andesitic ash possibly deposited from the Salida Volcano Field. The ash material is located on the ridge tops to the north and side ridges of the canyon as you approach the area of the Rincon Recreation Site through the west side of Howard.



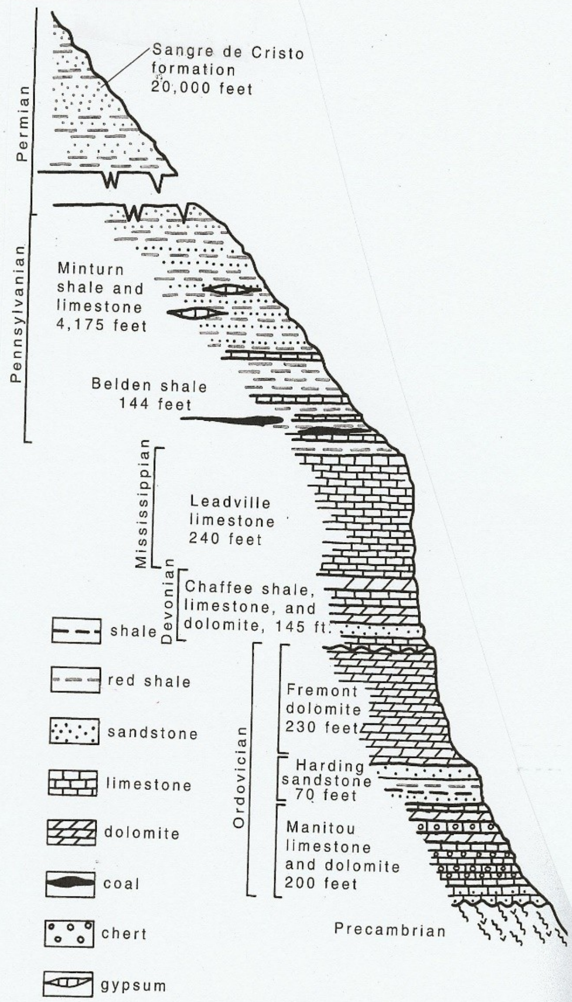
Geology along U.S. 50 between Canon City and Poncha Springs.

4. Halka Chronic and Felicie Williams 2002. Roadside Geology of Colorado, Second Edition. Missoula, Montana: Mountain Press Publishing Company, 169



Section along U.S. 50 between Canon City and Salida.

3. Halka Chronic and Felicie Williams 2002. Roadside Geology of Colorado, Second Edition. Missoula, Montana: Mountain Press Publishing Company, 168



Rock layers exposed near Wellsville in Arkansas Canyon include sandstone-shale and sandstone-limestone cycles in the Minturn and Belden formations. Wavy lines are major unconformities representing long periods of erosion. The Fremont and Leadville limestones form prominent cliffs.

5. Halka Chronic and Felicie Williams 2002. Roadside Geology of Colorado, Second Edition. Missoula, Montana: Mountain Press Publishing Company, 174

Rincon/Point Barr/Swissvale

- Beautiful Pennsylvanian and Permian red sandstone/shale/conglomerate redbeds dominate this area of Upper Big Horn Sheep Canyon. They are the uppermost sedimentary formation on the top of the east horst of the Rio Grande Rift that slopes upward here to the west and northwest and found to have been deposited up to 20,000 feet thick in some places. Other older sedimentary layers of the lower Pennsylvanian, including the black Belden shale, red Sharpsdale sandstone, greenish-brown Kerber shale, gypsum, and limestones of the Minturn Formation, are exposed around and west of Swissvale in the horst.
- All of the sedimentary layers above the redbeds have all been eroded away here and at the tops of some of the hills to the north and on some of the ridges replaced by a dark volcanic cap of andesitic ash possibly from the Salida or Guffey Volcano Field after the sediments were eroded away. From the Rincon Recreation Site, ash deposits are visible on the south canyon walls in bright light situations when the sun is not directly to the south. You drive through one of these ash flows between Rincon and west Howard, with the flow mostly visible on the north wall of the canyon. From the west Howard vantage point, you can look east and view the ash flow on the south side of the canyon, making a significant hill just to the south of the highway.

Howard

- The red rocks around you are the Pennsylvanian/Permian redbeds made up of sandstones, shales, conglomerates, and mudstones. They are the highest formation of sedimentary material remaining in this area on the top of the east horst of the Rio Grande Rift that tilts upward to the west and northwest. All higher formations have been eroded away and these beds are found to have been deposited up to 20,000 feet thick in some places in this area.
- In some areas on the tops of the hills to the northwest and west, dark volcanic materials possibly from the Salida or Guffey Volcano Field have capped some of the hills and ridges after the original sedimentary materials were eroded away. The occasional small white deposits you see northwest of Howard are travertine deposits
- To the north and northeast, notice beds of volcanic rhyolitic deposits lying on top of the redbeds sedimentary material. This generally reddish to white material may have come from the Aetna or Bonanza volcanic complexes farther to the west and southwest or the Grizzly Volcanic Complex to the northwest. It may be the oldest of the Tertiary volcanic flows in this area – the Ash Flow-1 Cooling Unit varying from trachyte to latite. Other areas of this volcanic material are visible along the east margin of the rift from Salida to Buena Vista.

Kerr Gulch/Pleasant Valley

- To the north of the highway across the valley, notice that on top of the Pennsylvanian/Permian Redbeds we have a large deposit of rhyolitic (reddish to white) material.
- This volcanic deposit is thought to have come from the west, possibly the Aetna or Bonanza volcanic complexes to the west and southwest of this location or the Grizzly Volcanic Complex to the northwest. It may be the oldest of the Tertiary volcanic flows in this area – Ash Flow-1 Cooling Unit varying from trachyte to latite.

Vallie Bridge

- Here on top of the rising east horst of the Rio Grande Rift, we find a mixture of limestone (both Mississippian and Pennsylvanian), conglomerates, and shale (Mississippian) along with the Permian Redbeds (the red sand and mudstone deposits found to have been deposited to up to 20,000 feet thick in parts of this area) capped with Badger Creek Tuff. These sedimentary rocks are deposited on top of the lower Paleozoic rocks that are exposed to the west in Upper Big Horn Sheep Canyon near Wellsville.
- The violent Front Range uplift to the east caught and curled upward the eastern end of the east horst of the Rio Grande Rift in this location so that we here see brought to the surface the same early Paleozoic limestone and shale layers that we see farther to the west from just east of Salida to Swissvale, including the Pennsylvanian/Permian Redbeds tilted and bent significantly upward to the east, opposite of what we see just west of here and opposite the tilt of the east horst.

Coaldale/Canyon Trading Post/Cotopaxi

- Coaldale is a major junction point of different geologic processes at work on the earth's crust. To the east, we have major crustal uplift activity that resulted in the creation of the Front Range of the Southern Rocky Mountains. To the west, we have major plate tectonic tensional activity that caused the creation of the Rio Grande Rift, its valley represented by the San Luis and Upper Arkansas River valleys in this region. To the west of Coaldale and prior to the rift valley itself, we enter the heavily faulted east uplift (horst) region of the rift and Upper Big Horn Sheep Canyon.
- To the east, we have the beginning of Lower Big Horn Sheep Canyon and the beginning of the deeply faulted Front Range uplift with the Arkansas River following a primarily northwest/southeast trending series of fault lines (a fault system) through the uplift. At this point, you see a high NW/SE trending ridge of beautiful basement Precambrian granitics with some dark metamorphosed rock (gneiss and schist) mixed in.
- To the north of Coaldale, the ridge forming the west side of the Front Range uplift can be seen running northwest to southeast to Coaldale and Highway 50. This ridge is made up of mostly beautiful tan basement granitics. The Pleasant Valley Fault, marking the west edge of the Front Range Uplift (the fault along which the west side of the Front Range uplift occurred), follows the west side of this granitic ridge.
- South of Coaldale, on the east slopes of the Sangre de Cristo Mountains (the rotated crustal blocks east of the Rio Grande Rift valley (San Luis Valley) forming the east horst uplift of the rift), limestone and gypsum cliffs (mines) can be seen – the limestone being the Leadville Formation of the upper Mississippian period.
- To the southeast of Coaldale the Arkansas River and highway take an abrupt left bend and enter straight into the hard granitic and metamorphic west wall of the Front Range uplift, turning from southeasterly to northeasterly. The river west of this point was cutting through softer sedimentary rock all the way from just west of Wellsville but now cuts through much harder rock. This presents a real geologic problem –why did the river not just continue southeasterly into the Wet Mountain Valley using a sedimentary rock course. There is no answer at this point and the problem is being studied by the USGS. One possibility is the geological explanations behind water gaps, of which this could be one.

- To the west and northwest, we see the up-sloping east horst of the Rio Grande Rift, here comprising the very southern end of the Mosquito Range/Arkansas Hills. Upper Big Horn Sheep Canyon starts at this point and runs west to its mouth just south of Salida. The canyon and Arkansas River run through a NW/SE trending fault system in the east horst uplift of the Rio Grande Rift, so the canyon here is not primarily made by the river but it found and made its way through this fault system.

Lone Pine/Texas Creek

- Farther west from Coaldale in Lower Big Horn Sheep Canyon in the faulted Front Range uplift we see a mixture of basement Precambrian granite along with granite metamorphosed into gneiss and schist, some early Proterozoic metasediments, and some veins of granite intruded into the metamorphic rock after metamorphosing of the original rock. The farther west you go from Texas Creek in Lower Big Horn Sheep Canyon, there is more granite mixed with the metamorphic rock - the ratio of granite to metamorphic rock increases more as one proceeds west through Lone Pine to Cotopaxi.
- In this area, the trending fault lines which the river follows switches to southwest/northeast, the canyon broadens, and it is less steep-walled. A rare (for this area) north/south trending fault, the Texas Creek Fault, is crossed at Texas Creek. This is a very unusual geologic feature to have a singular fault at such a contrary angle to the fault system but it is seen two more times between the Texas Creek Fault and the Royal Gorge. It might indicate that the fault was active from the time of the Larimide orogeny. The Texas Creek Fault proceeds both north and south from its crossing of the Arkansas River at Texas Creek. To the south, it proceeds to the Wet Mountain Valley.
- This less-steep walled area around Lone Pine displays a fine example of the primary way in which granitic rocs erode – spheroidal erosion with some spalling erosion as well. There are no better examples of spheroidal erosion along this entire stretch of highway.
- Between a mile and a mile and a half east of Texas Creek, the Arkansas River runs through a portion of the canyon made up of early Proterozoic meta-sedimentary rock. There is a large and beautiful deposit on the north and west walls of the canyon through this section. Some of the meta-sediment is filled with porphyroblasts, some of which appear to contain small garnets. The ground-mass of the meta-sediment is fine granitic material that has been metamorphosed and could be mistaken for a gneiss.
- In some areas on the tops of the hills far to the north, basaltic lava materials from volcanic eruptions in the 39-Mile Volcano Field to the north have capped the hills after the original sedimentary materials were eroded away. This darker gray material on the ridge tops to the north is visible as notches occur in the north wall (east or west from Texas Creek or west from Parkdale).

Pinnacle Rock

- Not far to the west of Pinnacle Rock, at a north/south to east/west sharp turn, we cross the Five-Point Fault on a highway bridge, another rare north/south trending fault for this area – possibly from the Larimide Orogeny time period This fault starts just south of the river up a small canyon but continues far north across Echo Park, thought to be a main contributor to the formation of Echo Park. On the north side of Echo Park, we observe mesas with a cap layer of basalt from the 39-Mile Volcano Field. The southern end of the volcano field is only five miles north from the Arkansas River. The turn in the canyon here in which the Arkansas River flows indicates that the fault system returns again to a northwest/southeast trending fault system.

- The rocks we see here east of the Five Points Fault deep in the lower canyon in the faulted Front Range uplift are basically Precambrian metamorphic basement rock (gneiss, schist, and metasediments), much from the early Proterozoic period with only a little basement granite with much of the visible granite from intrusions, after the metamorphosing, seen in the rock walls of the canyon around you.
- Pinnacle Rock and this surrounding area consists of a great deal of schist.

Five Points

- The rocks in this area deep in the lower canyon are all of the Precambrian period and mostly of the early Proterozoic metamorphic variety (gneiss and schist with little original or intruded veins of granitic material, and metasediments) that have been uplifted from deep within earth's crust by the Front Range uplift event. It is said that this are underwent a 10,000 foot or so uplift.
- Notice the veins of intruded granitic material, after the metamorphosing of the original basement granites, as seen in the walls of the canyon around you.
- On the south side of the observation deck for the rapids at the Five Points Recreation site, there is a fair amount of meta-volcanic material represented in the boulders.

Spikebuck

- We see around us deep in the lower canyon, within fault system the Arkansas River is following, the mixed granites and metamorphic (gneiss and schist) basement rocks of the Precambrian period uplifted from deep in the earth's crust by the front range uplift event
- Rocks in this area are more of the metamorphosed variety than the original granites, prior to metamorphosing, and granites intruded as veins after metamorphosing.
- In some areas on the tops of the hills to the north, basaltic lava materials from volcanic eruptions in the 39-Mile Volcano Field to the north have capped the hills after the original sedimentary materials were eroded away.

Parkdale

- To the west, we have the entrance to Lower Big Horn Sheep Canyon. It is the westward continuation of the front range uplift, is heavily faulted due in part to the uplift, and the Arkansas River follows this primarily northwest/southeast trending fault system through this Lower Big Horn Sheep Canyon (it did not erode this canyon). The canyon to the west consists of basement granitic and metamorphic rock (mostly gneiss, schist, and metasediments) of the early Proterozoic Precambrian period with granitic intrusions.
- To the west, at the edge of rising ridge of mountains lies the Else Fault, the third of the unique north/south trending faults of the Lower Big Horn Sheep Area. It is a major fault running south from here along the mountain ridge, creating the west side of the Webster Park syncline (about 3 miles wide and six miles long), and running north to create the west side of the larger Twelvemile Syncline and Twelvemile Park.

- Around you and to the east, we have the Mesozoic Morrison, Dakota, Graneros, Greenhorn, Carlisle, and Niobrara formation (sandstone/shale) rocks, trapped by the violent Front Range uplift, on top of the basement rock. This patch is significantly faulted and folded with wedges of the formations tilting at weird angles, even vertical and overturned. A number of faults emanate from the Parkdale area in almost all directions. There are no Paleozoic rocks underneath these sediments like we see to the west of Coaldale and east of the Royal Gorge – they were completely eroded away before these formations were deposited or were never deposited here (undetermined to date). Both Webster Park and Twelvemile Park are called "outliers" – they consist of sedimentary rock from after the Paleozoic period bounded on all sides by the much older hard Precambrian basement igneous rock with none of the Paleozoic period rocks that are supposed to be there actually there.
- To the east and south, we have the continuation of the Front Range uplift in the ridges seen in the distance (the Wet Mountains to the south). The Arkansas River continues to follow some deep faults into the Royal Gorge area and toward Canon City. Just like at Coaldale, the river flows straight into much harder crustal igneous rock than the sedimentary rocks of Webster Park. A more natural flow for the river appears to have been a continuation south along the east edge of Webster Park and east around the south side of the Royal Gorge Arch and out onto the plains. Again, we have a mystery somewhat like at Coaldale –steering faults, a water gap, or what else could have been the cause of what the river wound up actually doing here..
- In some areas on the tops of the hills to the north, basaltic lava materials from volcanic eruptions in the 39-Mile Volcano Field to the north have capped the hills after the original sedimentary materials were eroded away.

Royal Gorge

- The Royal Gorge, one of the deepest canyons in Colorado (1250 feet), is a large block of a mixture of Precambrian gneiss, migmatitic gneiss, schist, and intruded by granite, granodiorite, quartz diorite, and gabbro. We see a diorite dike to the east. We can see that the gorge area is a north-to-south trending arch, like a laccolith dome or an anticline, 6 miles wide by 10 miles long called the Royal Gorge Arch. The formation of the gorge is hypothesized by some to have occurred during the Pliocene period (a hypothesis that links the gorge to uplifting by a northwest trending fault lines that caused a rise or uplift westward to the Poncha Springs area and the Methodist Mountain complex, deflecting the Arkansas River to the southeast rather than through the San Luis Valley).
- Looking to the east and west up and down the gorge, we see granite around us here today that appears to have intruded up along cleavage planes in the gneiss and schist, creating intrusion columns and granite masses up to hundreds of feet thick. What you see is referred to as **injection gneiss**. Notice to the west that the gneiss and schist seem to be somewhat more predominant than right in front of us.
- The flat rim of the Royal Gorge, as we can see around us, is an undulating plain at basement rock level, possibly worn down during an erosion interval at the end of Precambrian time.
- The road on which we enter first crosses granite and, then, a band of brownish-gray metamorphic rock where many large pegmatitic dikes contain unusually large crystals of feldspar, quartz, and both muscovite and biotite mica (as at the Mica Lode Mine).

Crystals can grow exceptionally large with a high amount of hydrothermal flow, slow cooling, and lots of room to grow.

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.