# GEOLOGY ALONG THE OURAY AREA
## June 1-2, 2019

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Photochrom print of photograph by W.H. Jackson of Ouray looking south at Hayden Mountain. The photograph was taken in 1901 from near The Blowout stock.

## OVERVIEW OF GEOLOGIC SETTING OF OURAY

Sometimes called the “Switzerland of America” the town was named for Chief Ouray who was leader of the Ute Tribe around 1875. The town was first settled by prospectors in 1875 and was incorporated in October of 1876. It was the hub of the Ouray mining district for nearly 100 years. Today the economy of Ouray is based mostly on tourism with mining providing a smaller component in the past 10 years.

The town is nestled in a glacial valley in a small mountain park at ~7800 feet at the confluence of the Uncompahgre River and Canyon Creek. Prominent peaks such as Hayden Peak, Gold Hill, Cascade Mountain, and Twin Peaks surround the town. Ouray County was founded in 1883 and is reported to be the first county created following Colorado statehood in 1876 (Dawson, 1954). The population was around 400 citizens, and nearly doubled in 1876 when precious metal deposits were discovered. The town was the hub of mining activity from 1878 to 1986 in the Uncompahgre mining district. Burbank and Luedke (2008) note that this mining in this district produced 2,007,872 ounces of gold, 49,110,490 ounces of silver, 26,609 short tons of copper, 148,253 short tons of lead, and 78,391 short tons of zinc.

An extensive record of geologic events is exposed in this area (Fig. 1). The oldest rocks in the area are quartzite (pCuq on Luedke and Burbank, 1962) and phyllite (pCus on Luedke and Burbank, 1962) of the Uncompahgre Formation. These rocks were deposited in a marine basin between 1.7 and 1.43 Ga (Gonzales and Van Schmus, 2007). Contraction on the southern margin of Laurentia led caused thrusting, folding, and polyphase deformation of the rocks in the Uncompahgre Formation. The Proterozoic quartzite and phyllite of the Uncompahgre Formation are prominently exposed on the footwall of the Ouray fault south of town.

The Ouray hot springs are heated by geothermal waters that ascend along the Ouray fault, with hot water piped from the Box Canyon area to the Ouray Hot Springs Park. Isotopic and geochemical data from the thermal waters lend evidence for mantle contributions to the gas content of the waters.

Near Box Canyon falls the Uncompahgre Formation is intruded by a diabase dike (d on Luedke and Burbank, 1962) of uncertain age. Attempts to constrain the crystallization age of the dike with U-Pb zircon analyses and Ar-Ar analyses on hornblende were not successful. This dike could be correlative with diabase dikes of similar trend in the Black Canyon of the Gunnison whose age was constrained with K-Ar analyses on potassium feldspar at 510 ± 60 Ma (Hansen and Peterman, 1968; Hansen and Hansen, 1981).

The steep canyon walls that bound Ouray exposed about 4,000 feet (1200 meters) of Paleozoic and Cenozoic sedimentary rocks dipping gently to the north and northwest. The sedimentary section is blanketed by a thick sequence of gray volcanic rocks that comprise the Oligocene San Juan Formation, and is locally intruded by sills of ~65 Ma granodiorite (Figs. 2, 3). The oldest unit in the section is the Devonian Elbert Formation. About 1,000 feet (305 meters) of gray and buff strata above the valley floor to the west, and northeast are the sandstone, shale, and limestone layers of the Pennsylvanian Hermosa Group. Above these layers are the red beds of the Permian Cutler Formation and the Triassic Dolores Formation (Chinle equivalent). An angular unconformity separates these two formations and suggests that there were several episodes of uplift along the Ouray and other local faults in the Permian and early Triassic, around 245 million years ago (Fig. 2). Above the Dolores are the Jurassic Entrada, Wanakah, Morrison formations, and the Lower Cretaceous Dakota Formation. The upper part of the exposed section is capped by Late Cretaceous Mancos Shale (Km on Luedke and Burbank, 1962), Oligocene Telluride Conglomerate (Tt on Luedke and Burbank, 1962), and andesitic volcaniclastic rocks and lavas flows of the Oligocene San Juan Formation (Tsj on Luedke and Burbank, 1962). The Telluride Conglomerate is composed of interbedded conglomerate and sandstone that were deposited by streams and debris flows over the area during the Oligocene (Harraden et al., 2007). The unit thickens from 50 feet southeast of Silverton to over 500 feet near Telluride. The Telluride Conglomerate preserves an unroofing sequence with basal units dominated by Paleozoic sedimentary clasts grading into upper dominated by Proterozoic basement from the adjacent Needle Mountains (Gonzales et al., 2005). Detrital zircon analyses constrain a depositional age for the Telluride Conglomerate from 31.5 to 28.0 Ma (Donahue et al., 2011). Near Telluride, rhyolitic to andesitic volcanic fragments contained in the upper part of the Telluride Conglomerate yielded U-Pb zircon ages of 68.98 ± 0.86 Ma and 65.70 ± 0.75 Ma (Mudge and Gonzales, 2016) revealing the existence of a Laramide volcanic center in the area that is now nowhere exposed. Burbank and Luedke (2008) reported that the San Juan Formation in this area is composed of interbedded tuff breccias, conglomerates, flow breccias, reworked tuffs, and basaltic andesite lava flows. The age of the San Juan Formation in the western San Juan Mountains was previously was thought to have been deposited from 35 to 30 Ma from stratovolcanoes to the south and east but the age was not well constrained. New U-Pb zircon age data from lava flows and flow breccia deposits at Coxcomb Peak east of Ridgway are constrained at 30.45 ± 0.18 Ma (unpublished data from D. Gonzales), indicating that the Telluride Conglomerate must be older than ~30.4 Ma.

The stratified section is intruded by a mafic to felsic dikes, sills, and stocks (Figs. 3, 4). The most prominent of these plutons are visible to the west where sills of granodiorite (gp on Luedke and Burbank, 1962) are exposed at Twin Peaks and the walls of Oak Creek Canyon and Canyon Creek. These sills are related to the Blowout stock which forms a nucleus of mineralization east of Ouray. The Blowout stock and related sills were emplaced ~65 Ma (Gonzales, 2015). The ages of many of the other intrusive masses in this area are not well constrained. Just north of Ouray, near the Skate Park, stratified rocks are cut by several “clastic” dikes (cl on Luedke and Burbank, 1962) that fill east-west trending fractures and have a close spatial relationship to granodiorite dikes. The clastic dikes contain angular to rounded to subrounded granules to cobbles of Proterozoic and younger rocks that include quartzite, phyllite, sandstone, siltstone, shale, and intrusive rocks along with fragments of quartz, alkali feldspar, biotite and chlorite. The dikes range from < 0.25 m to 4 m in thickness and are matrix to clast supported with a subtle alignment of fragments in some outcrops. The matrix is fine to coarse grained and has a green color imparted by secondary epidote and chlorite. In some outcrops calcite fills cavities and spaces in the dikes.

Burbank and Luedke (2008) concluded that these dikes formed by explosive release of hydrothermal fluids and gasses during intrusion of Cenozoic plutons.

The Ouray area lies on the fringes of caldera complexes in the western San Juan Mountains. Volcanic eruptions from stratovolcanoes in the area preceded caldera eruptions. These pre-caldera deposits are preserved in the ~30 Ma San Juan Formation which dominates the volcanic record outside the margins of the caldera complexes (Fig. 1).

The San Juan magmatic locus is the largest erosional remnant of the Southern Rocky Mountain volcanic field (SRMVF) (Fig. 5). Between approximately 37 and 23 Ma at least 28 silicic ignimbrites (Fig. 6), with individual volumes ranging from 100 to 5000 $km^3$, erupted from collapse calderas in southwestern Colorado and northern New Mexico (Lipman and Bachmann, 2015). The initial caldera eruptions between 37 and 33 Ma were located to the northeast within the present-day Sawatch Range. Super-eruptions then migrated to clusters of calderas in the southeastern, central, and western regions of the San Juan locus (Lipman et al., 2015). Prior to, during, and after caldera eruption, dominantly intermediate composition lavas and volumetrically minor tuffs erupted from stratovolcanoes and associated vents throughout the field (Fig. 7).

Calderas in the western San Juan Mountains make up the westernmost eruptive centers of the SRMVF. The San Juan and Uncompahgre calderas are the oldest and largest identified calderas in the area (Fig. 8). These calderas simultaneously collapsed during eruption of the 28.45 ± 0.03 Ma Sapinero Mesa Tuff, a 1000 $km^3$ crystal-poor rhyolite (Bove et al., 2001) (Figure 6). The Sapinero Mesa Tuff (and its intracaldera equivalent called the Eureka Member) is unusual for regional ignimbrites in that it erupted from two calderas that coalesced during collapse (Lipman et al., 1973; Steven and Lipman, 1976). During and following resurgence, the San Juan-Uncompahgre caldera complex was partially filled with post-caldera lavas and sediments collectively known as the Silverton Volcanic Series. This unit includes the lower Burns Member lavas and tuffs, an upper Pyroxene Andesite Member, and interbedded volcaniclastic rocks of the Henson Formation. Nested within the San Juan-Uncompahgre caldera complex are two younger calderas. The Silverton caldera collapsed at 27.59 ± 0.07 Ma during the eruption of the Crystal Lake Tuff. Subsequent erosion has removed the intracaldera Crystal Lake Tuff and any post-caldera lavas, but outflow tuff is ponded within the older San Juan-Uncompahgre caldera complex.

Three western San Juan regional ignimbrites (29.3 Ma Ute Ridge, 28.6 Ma Blue Mesa, and 28.6 Ma Dillion Mesa) predate the eruption of the Sapinero Mesa Tuff. Source calderas have not been identified, but outflow patterns suggest that eruptive centers may be buried beneath or were obliterated by the identified calderas of the Western San Juan cluster (Lipman et al., 1973).

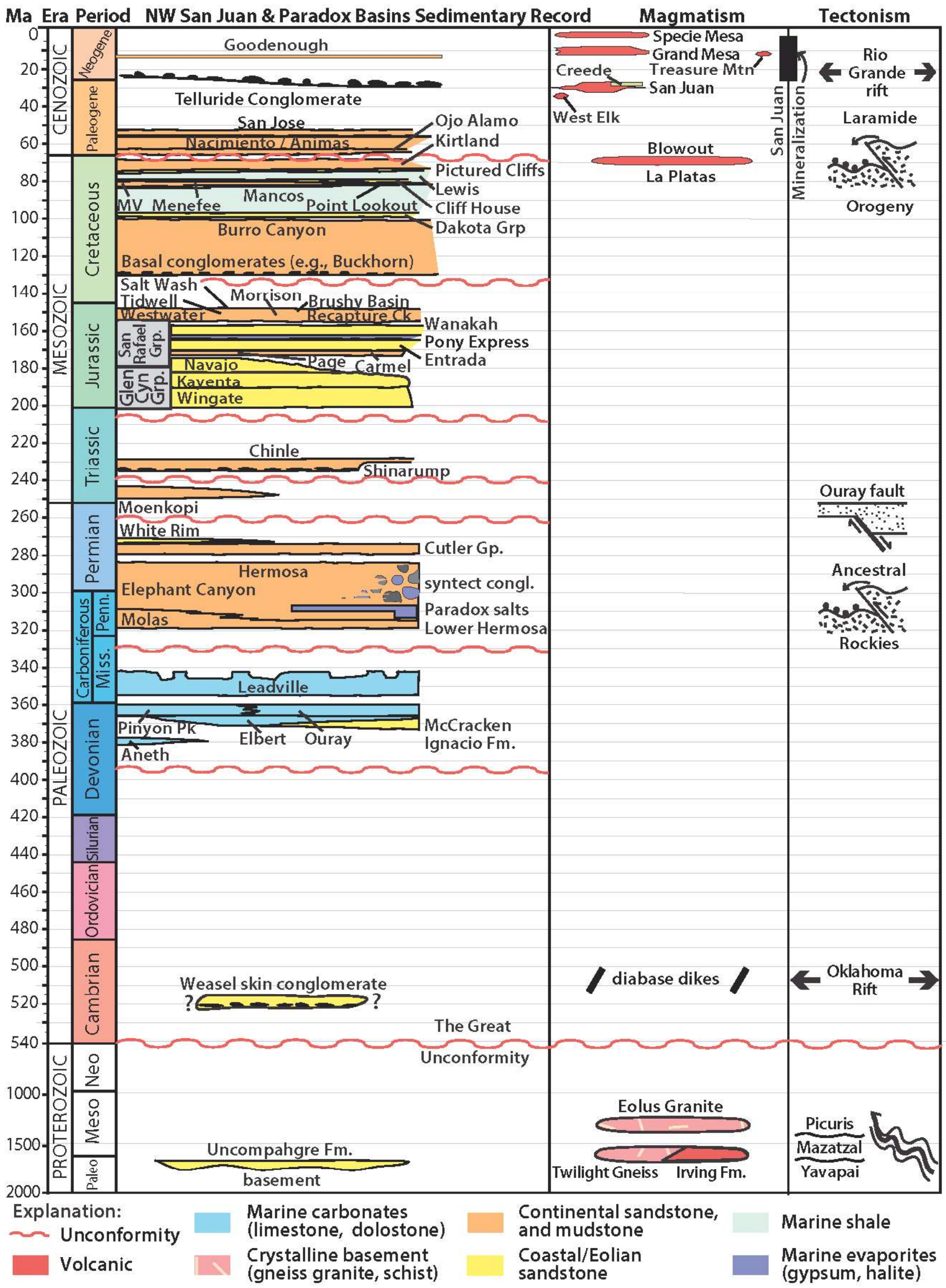


**Figure 1.** Stratigraphy of the western San Juan Mountains, adapted from Raynolds and Hagadorn (2016).

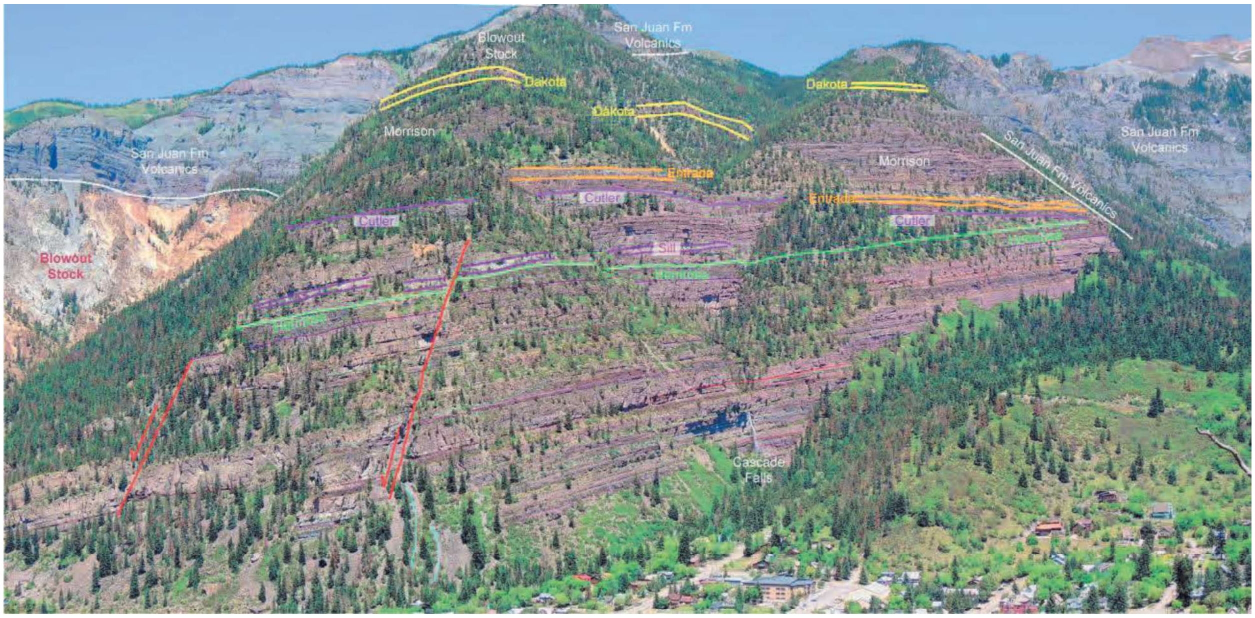


**Figure 2.** Pennsylvanian to Oligocene rock units exposed east of Ouray. Compiled by Steve Cumella.

**Figure 3.** View of the Paleozoic through Cenozoic section exposed west of Ouray. The white lines mark the approximate lower and upper contacts of a ~65 Ma granodiorite sill. Above the sill are gray pinnacles of Twin Peaks composed of Oligocene San Juan Formation. Remnants of the Telluride Conglomerate are preserved locally at the unconformity separating Phanerozoic strata from San Juan Formation (see Fig. 1). The range-bounding Ouray fault occurs in the drainage (Box Canyon) between cliffs of Pennsylvanian Hermosa Group strata on the right (N) and basement rocks of the Uncompahgre Formation on the left (S). This fault has N-down normal separation of several hundred meters in the lower Paleozoic rocks with throw decreasing higher in the section in Mesozoic rocks suggesting a Permian ancestry (Soreghan et al., 2012) with minor Laramide and mid-Tertiary reactivations (Fig. 1).

**Figure 4.** View, looking north, of the historic town of Ouray. Note the orange exposure of rock to the right (northeast). These altered rocks are mostly within the ~65 Ma granodiorite pluton called The Blowout (Gonzales, 2015). Sills of similar composition occur below Twin Peaks and Sister Peak, and in the steep western walls of Canyon Creek. Photograph is courtesy of Robert Powell.

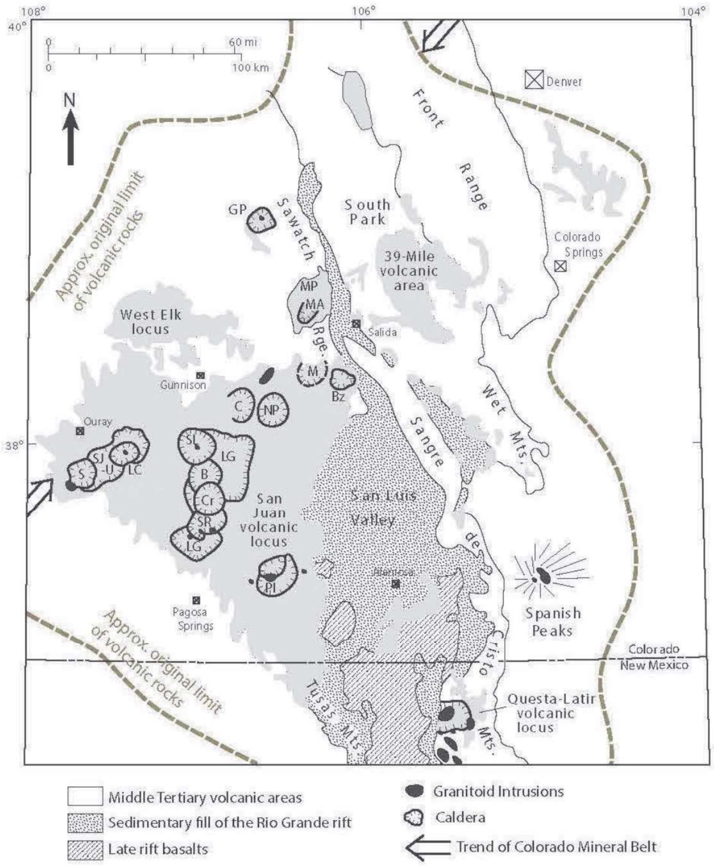


**Figure 5.** Simplified geologic map showing the Southern Rocky Mountain volcanic field and adjacent geologic features (modified from Lipman and Bachmann, 2015). Calderas are: B-Bachelor, Bz-Bonanza, C-Cochetopa, Cr-Creede, GP-Grizzly Peak, LC-Lake City, LG-La Garita, M-Marshall, MA-Mt. Aetna, NP-North Pass, PL-Platoro, S-Silverton, SJ-U-San Juan-Uncompahgre, SL-San Luis, and Sr-South River. Mt. Princeton (MP) is the largest mid-Tertiary intrusion in CO.

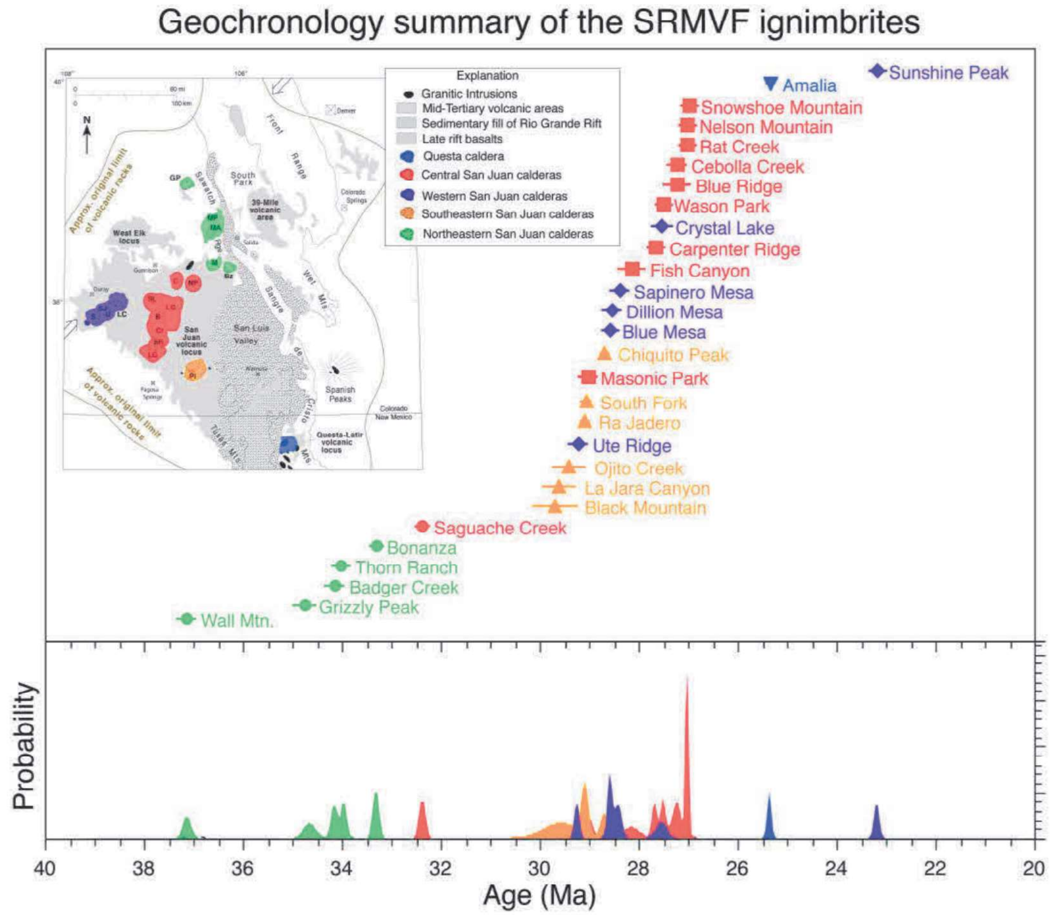


**Figure 6.** Geochronology summary of the SRMVF (from Lipman, 2007, Lipman and McIntosh, 2008, and Lipman et al., 2015). All ages reported relative to FC-2 equal to 28.201 Ma (Kuiper et al., 2008).

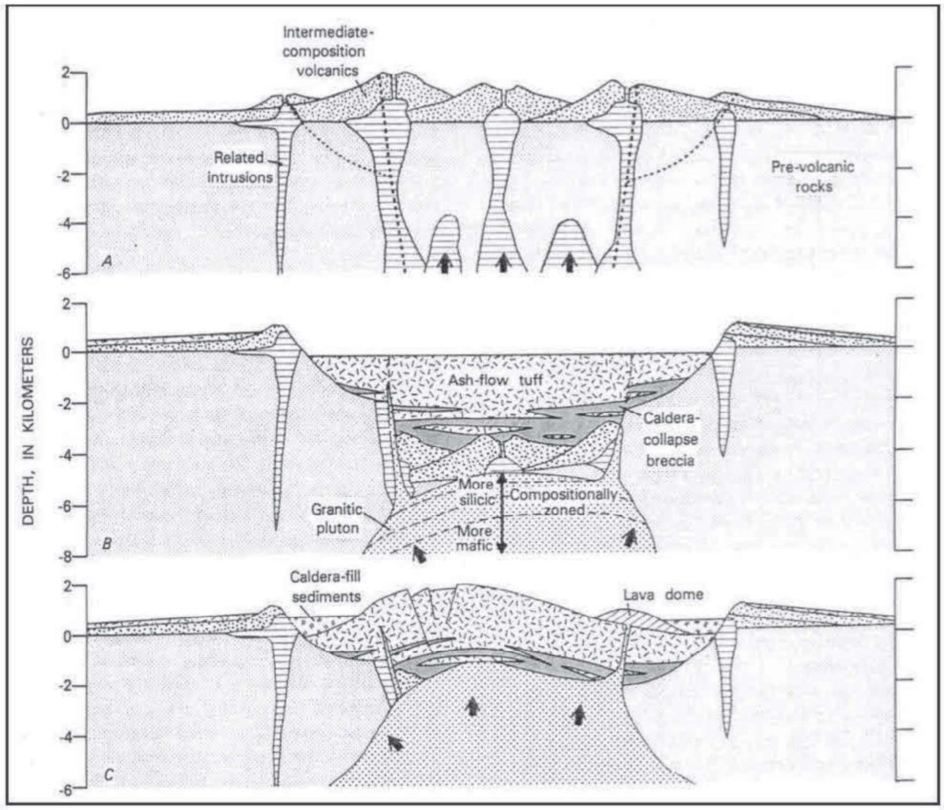


**Figure 7.** Generalized caldera evolution model from Lipman (1984). Many components of this model were developed in the west- ern San Juan caldera cluster. A) Precaldera volcanism the produced intermediate to felsic lava flows, pyroclastic deposits, and lahars of the ~30 Ma San Juan Formation. This stage of caldera evolution includes small volume eruptions, dominantly intermediate in composition, from central volcanoes. B) Syn-caldera volcanism. Cross-section shows geometry of the caldera immediately after collapse. Caldera subsidence is typically between 2-5 km. Caldera diameter may range from a few kilometers to as much as 75 km. C) Post-caldera volcanism. Following collapse, volcanism continues with numerous small volume eruptions similar to those that characterize pre-caldera volcanism. Lakes may form within the caldera depositing sediments that are often interbedded with ashes and lavas erupted from post-caldera domes. Some calderas exhibit resurgence, in which the intracaldera sequence is uplifted by buoyant magma to form a large dome. Numerous intrusions are commonly emplaced during this stage of caldera evolution.

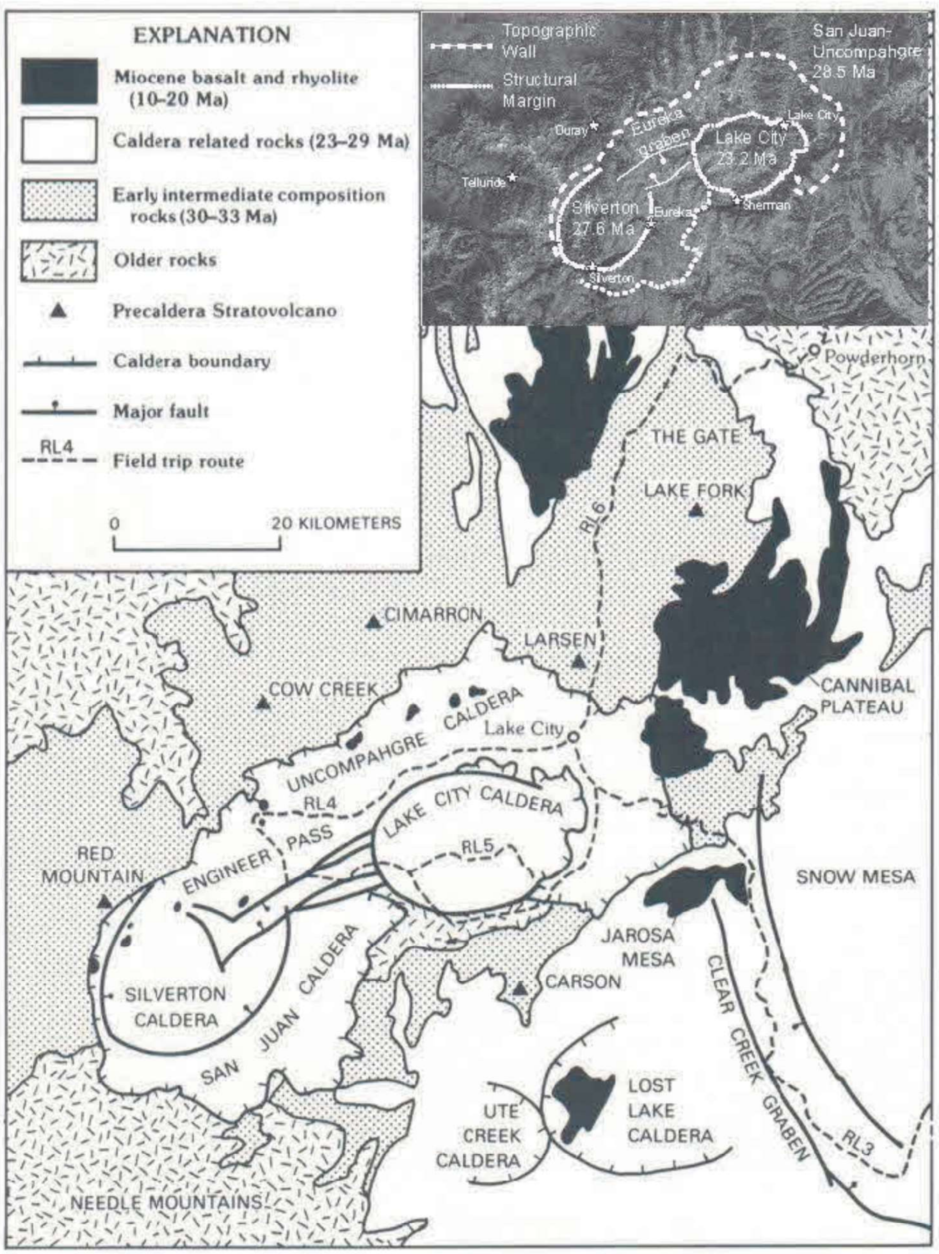


**Figure 8.** Generalized map of the western San Juan Mountains (from Hon and Lipman, 1989). Field trip route corresponds to that of the 1989 IAVCEI conference. The Google Earth view (upper right) shows the location of calderas relative to major towns. Erosion has exposed the ring-faults along the structural margin of the Silverton and Lake City calderas. In contrast, segments of the topographic wall have been identified for the San Juan-Uncompahgre caldera. The Eureka graben is the keystone graben along the crest of the San Juan-Uncompahgre resurgent dome.

## Day 1 Logistics

Day 1 of the trip focuses on the Proterozoic basement history along with discussion on Paleozoic to Mesozoic stratigraphy. On our last stop we examine a dike that is part of the Cenozoic magmatic record.

**Meet at the Ouray Hot Springs parking area at 8:00 am, get organized to leave at 8:15 am.**

8:15 AM - 8:30 AM – Drive to Switzerland of America pullover
8:30 AM - 9:00 AM – Overview of Geology of Ouray
9:00 AM - 9:15 AM – Drive to Bear Creek Falls
9:15 AM – 10:45 AM – Proterozoic units and structures (Climax Creek)
10:45 AM - 11:00 AM – Drive to Box Canyon falls visitor center, bathroom break
11:00 AM - 11:15 AM – Drive to Public parking area near CDOT
11:05 AM - 12:00 AM – Box Canyon hike
12:00 - 1:00 PM- Lunch at Box Canyon Fall visitor parking area
1:00 PM -1:15 PM- Drive to parking area for Baby Pools
1:15 PM – 2:15 PM – Explore the lower Paleozoic stratigraphy exposed in Portland Creek
2:15 PM – 2:30 PM – Drive to parking area for Cascade Falls Park
2:30 PM – 3:30 PM – Discussion on Pennsylvanian-Permian geology at Cascade Falls
3:30 Pm – 4:00 PM – Drive to parking area to about 15 miles north of Ouray, "Dike" wall
4:00 Pm – 5:00 PM – Jurassic to Triassic rock units cut by Cenozoic mafic dike
5:00 PM – 5:15 PM – Return to Ouray

**Departure time:** Vans and some personal cars will leave from the Ouray Hot Springs parking lot at 8:15 AM.

**Stops:** Short to moderate hikes are planned at each stop. Driving times between stops vary from as little as 15 minutes to as much as 30 minutes. Please plan accordingly. Restroom facilities are limited outside the town of Ouray.

**Road Guide for Day 1**

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Meet at the Ouray Hot Spring parking area at 8:30 am. Arrange carpools at this time. This is the only restroom stop available until lunchtime. A 10:30 bathroom break is listed on the schedule.

Drive pass the turn off to Box Canyon. The view east is of the large bowl-shaped valley, known as the Amphitheater. The gray rocks on your right in the Amphitheater are the Oligocene San Juan Formation (Fig. 9). The reddish rocks on your to the north are the Hermosa Formation (Pennsylvanian) and younger strata. The debris in the amphitheater is from a post-glaciation landslide.

**Figure 9.** A view of The Amphitheater on the southeast edge of Ouray. The gray “hoodoo” cliffs are in the San Juan Formation. The heavily timbered area below (west) of the cliffs are landslide debris. Photograph is courtesy of Robert Powell.

**Switzerland of America pull off.**

This location offers a fantastic view of the entire rock record in the Ouray area. A view to the west provides a glimpse of Uncompahgre River gorge. The gorge was carved out of quartzite and phyllite of the Uncompahgre Formation by the erosive action of glaciers and streams. The rocks of the Uncompahgre Formation (Fig. 10) were deposited in a marine basin, which was then deformed and metamorphosed between 1,690 and 1,460 Ma. The section was tipped up on edge as revealed by the near vertical layers. The formation is thought to be over 8,000 feet (2,448 meters) thick. These Proterozoic rocks represent part of an east-west trending, uplifted fault block known as the "Sneffel's" horst, which is bounded on the south by the Dunmore fault (Kelly and Silver, 1946) and on the north by the Ouray fault. The tectonic history of the Sneffels Horst has had a profound influence on the geology in this region. From Ironton Park, north towards Ouray, the Paleozoic-Mesozoic section is absent and the San Juan Formation rests unconformably on the Uncompahgre Formation.

Near Ouray, the hanging wall of the Ouray fault preserves a wedge of Paleozoic to Cenozoic sedimentary rocks that thickens to approximately 800 feet thick (245 meters) just north of town. This section reveals strata from the Devonian Elbert Formation through the Cretaceous Mancos Shale with some remnants of the Oligocene Telluride Conglomerate. The unconformity on top of the Proterozoic rocks is tilted toward the northwest, in certain localities marks the lower boundary of late Tertiary mineralized veins, and near Ouray constitutes the upper boundary of late Cretaceous mineralization.

The scarp of the Ouray fault is beautifully exposed on the east side of the road; the northern structure of the "Sneffel's" block (Fig. 11). Note the tilted beds of the Leadville Limestone exposed in the hanging wall of the Ouray fault on the east side of HW 550 N. At this point the scarp is "obsequent" defined by Devonian-Mississippian limestones exposed in the hanging wall of the fault being topographically higher than the hard and resistant rocks of the Uncompahgre Formation in the footwall (south). The limestones may be more resistant in this area because they are silicified from hydrothermal activity and contain numerous veinlets and stock work breccias filled with quartz.

Look south for a fantastic view of Mt. Abrams (Fig. 12) the starting zone for the East Riverside avalanche path, the deadliest and most notorious of snow avalanche paths on Red Mountain Pass.

To the southwest the steep cliffs on the flank of Hayden Peak expose a northeast-trending fault that displaces the lower Paleozoic section against the Proterozoic rocks with the downthrown thrown on the west side of the fault. Hikers can view the section to the west with lower Paleozoic rocks faulted against Proterozoic rocks (Fig. 13).

The relatively flat top of the hanging wall defines an area known as Mineral Farm mine, discovered in 1876 by Augustine W. Begole. Burbank and Luedke (2008) noted that the deposits at Mineral Farm mine formed by hydrothermal leaching along bedding planes and fractures in the Leadville Limestone and Molas Formation, creating cavities in which silver-lead ore minerals were deposited. Leaching of the Leadville Limestone along fracture channels, just beneath the Molas Formation formed solution breccia and large cavities in which most of the mineralization was concentrated. Burbank and Luedke (2008) reported that mineralization at the Mineral Farm mine was Ag-Pb-Zn (chalcopyrite, tetrahedrite, pearcite, and pyrargyrite) ore found in vein and replacement deposits. Movement of hydrothermal fluids associated with mineralization are thought to have migrated along fractures on the south side of the Ouray fault to favorable zones in the Leadville Limestone created by pre-mineralization leaching along fractures in the underlying Proterozoic rocks. Grades as high as 20% Cu and 800 opt Ag are reported from the mine but produced less than $1,000,000 of ore.

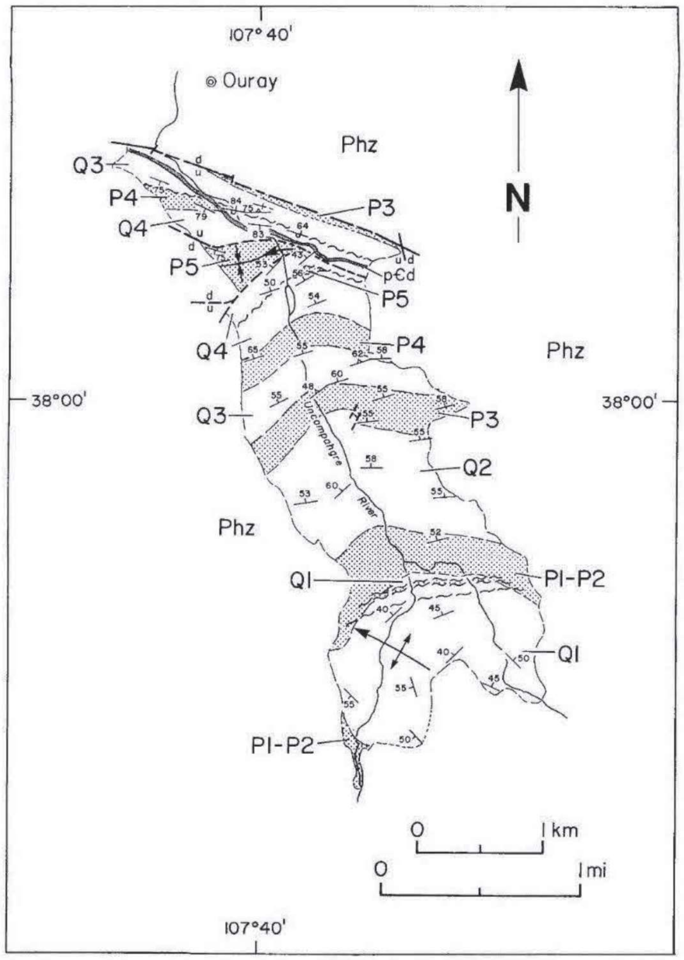



**Figure 10.** Geologic map taken from Harris (1976) showing the proposed stratigraphic relationships and structures in the Proterozoic Uncompahgre Formation. The oldest units in the section is designated Q1-P1 and the youngest are Q4 and P5.


**Figure 11.** A view of Ouray fault looking southeast from the area above Box Canyon Falls. The approximate trace of the fault is shown by the white line. The exposure of the fault east of the highway has the hanging wall (left) is elevated relative to the footwall (right) as the result of differential erosion along the fault scarp.

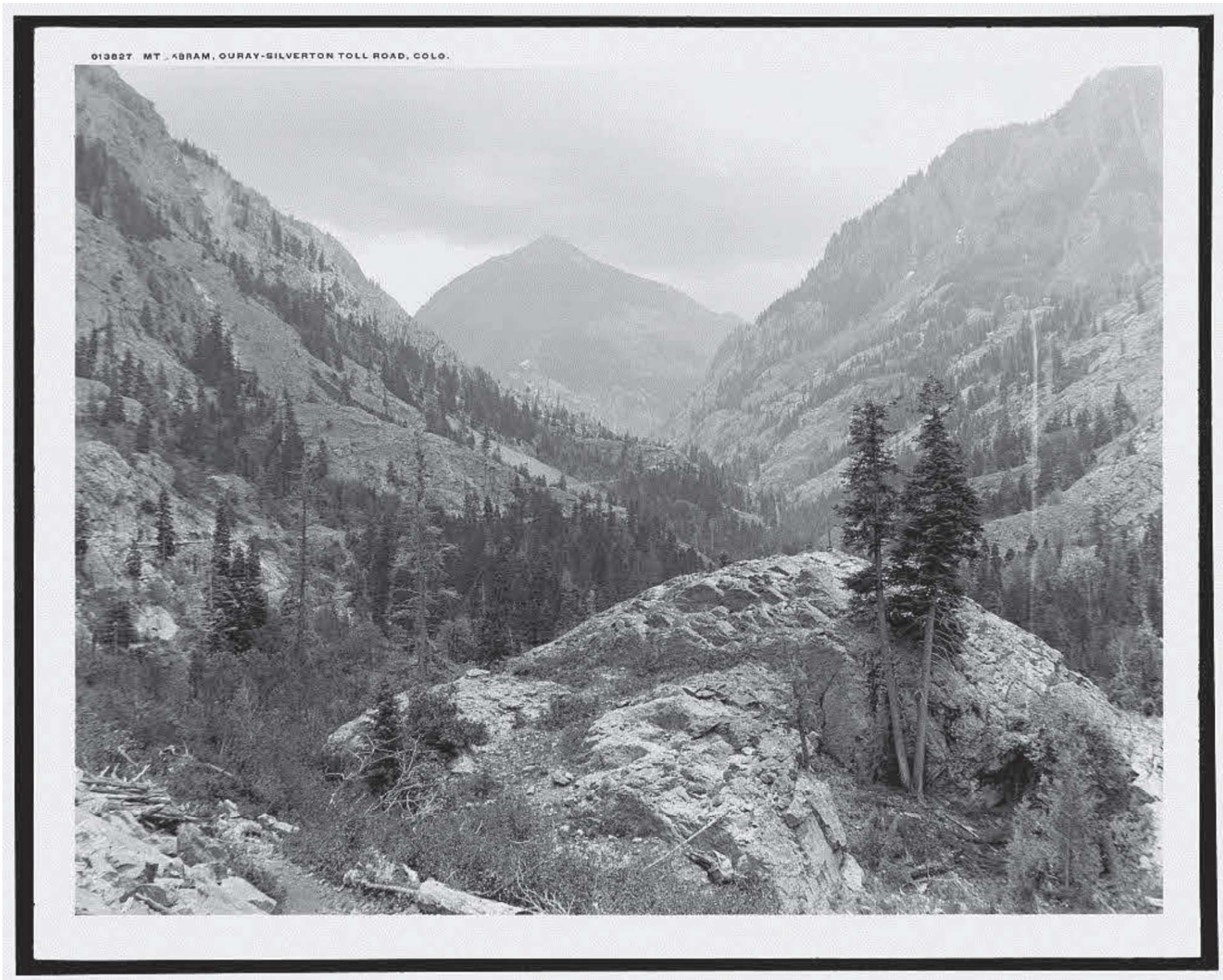



**Figure 12.** Photograph of Mt. Abrams from near Ouray looking south as viewed by W.H. Jackson in 1900. The Proterozoic Uncompahgre Formation is exposed in the foreground. Photograph was downloaded from the Library of Congress. The basal part of Mt. Abrams is composed of Oligocene San Juan Formation cut by Miocene intrusions which are capped by volcanic rocks (Henson Formation and Sunshine Peak Rhyolite; Burbank and Luedke, 1962) formed during caldera eruptions 28.5 to 27.6 Ma (Lipman et al., 1973; Steven and Lipman, 1976; Lipman, 1989; Bove et al., 2001; summary in Lipman, 2007).

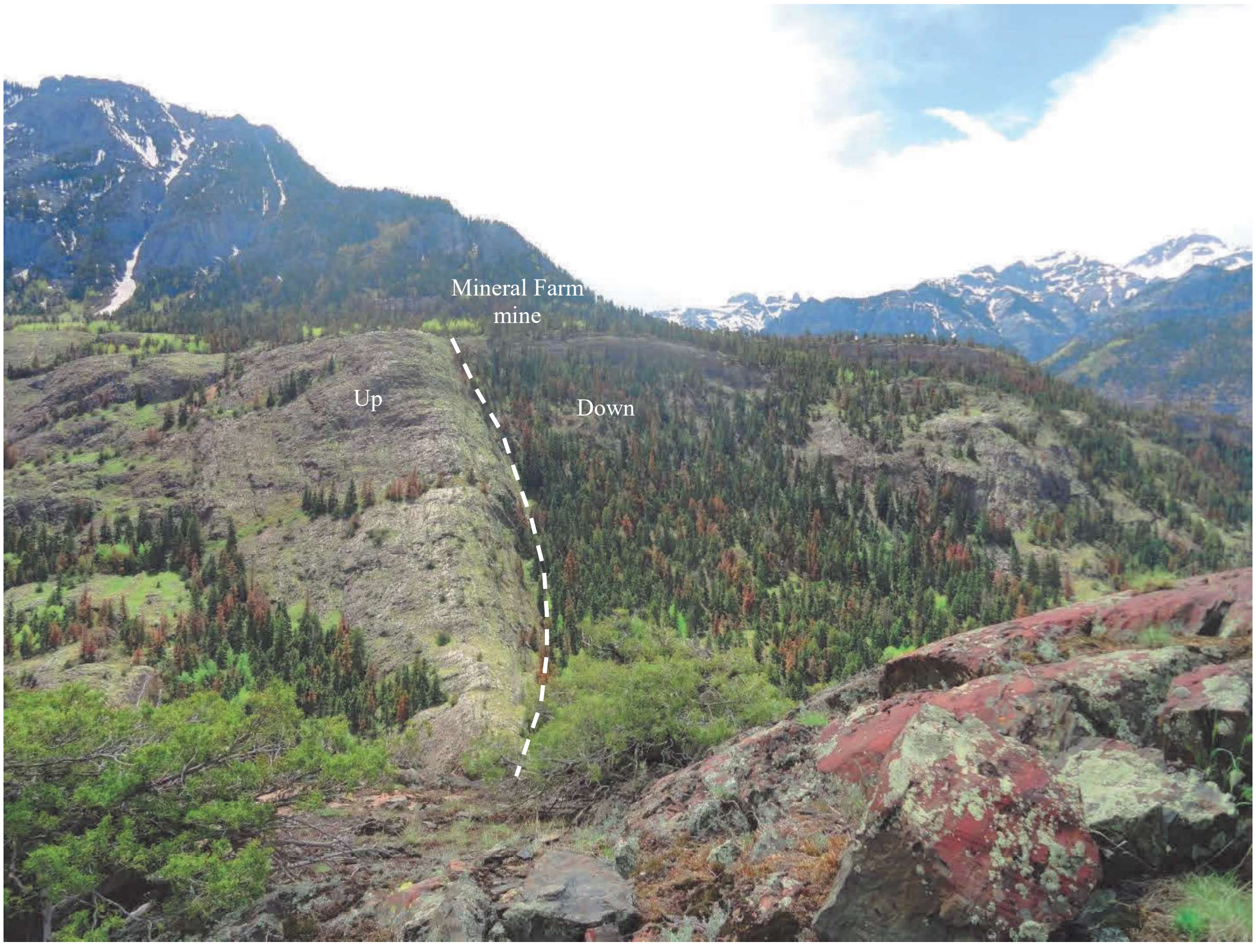



**Figure 13.** Looking southwest towards the base of Hayden Mountain. The highlighted fault scarp has a steep dip to the northwest with the downthrown side to the west (right on figure). This fault places the lower Paleozoic section down against the Proterozoic rocks, but further to the southwest it splays and terminates at the base of the Pennsylvanian Hermosa Group (Luedke and Burbank, 1962). The exact timing of this fault is uncertain. The Mineral Farm mine is situated on the bench midway in the photo where lower Paleozoic rocks cap the Proterozoic Uncompahgre Formation on the hanging wall of the fault.

**Approaching the Bear Creek tunnel**. Exposures of steep-dipping quartzite in the Uncompahgre Formation in the road cut on east side of highway.

Outcrop of quartzite and phyllite of the Uncompahgre Formation. On the east side of the highway, about 50 feet east of the pavement, veins of quartz containing sulfides minerals are exposed, and there are several mine dumps that are still present.

**Tunnel on Highway 550 N.** The tunnel is driven into phyllite and quartzite of the Uncompahgre Formation. Good exposures of phyllite are exposed along the east side of the highway. The Bear Creek trailhead starts at this point, and takes hikers to the unconformity between the Proterozoic rocks and San Juan Formation to the east. The highway is in the axial zone of the macroscopic fold in the Uncompahgre Formation.

**Bear Creek Falls pull off**

Steeply inclined phyllite in the Uncompahgre Formation is exposed in the steep and narrow Bear Creek canyon to the east. Fine laminations and bedding are preserved in the rocks despite having several generations of mesoscopic folds (F1 is isoclinal). On the west side of the river canyon, relict megaripples (Fig. 14) are exposed on a steep-dipping bed of quartzite in the Uncompahgre Formation. The Uncompahgre River canyon was mostly carved by glaciers that advanced to the north. The final terminal moraine related to glaciation is at Ridgway, about 20 miles north of Ouray.

Bear Creek (Fig. 15) drainage is a hanging valley carved by glaciers. The ice was estimated to be over 3000 feet thick here where Otto Mears had his toll station for the Million Dollar Highway. The falls drop about 200 feet to the Uncompahgre River below. Bear Creek trail is cut into the steep cliffs on the north side of Bear Creek. The trail served mines such as the Grizzly Bear mine, and provided supplies to the miners in the region. Remnants of tramways and cable systems that were erected across the steep walls of Bear Creek are still visible today.

Sares and Gleason (2000) noted that at Bear Creek Falls, avalanche control is done with a 105 mm howitzer. The East Riverside and Mother Cline avalanche paths are mitigated by launching explosives into the starting zones to release the avalanches while the road is closed.

Memorial to Otto Mears, “Pathfinder of the San Juan”. Otto Mears was instrumental in providing access into the rugged mountains by constructing toll roads (Fig. 16) and narrow gauge railroads into the towns and mining camps in the region in the late 1800’s and early 1900’s. He built a toll road from Ouray to Ironton Park in 1881, which opened a supply route to the miners in the Red Mountain district. This section of the highway was built in the 1920’s, costing around $1,200,000 and giving rise to the name “Million Dollar Highway” which is now applied to the stretch of highway from Silverton to Ouray.

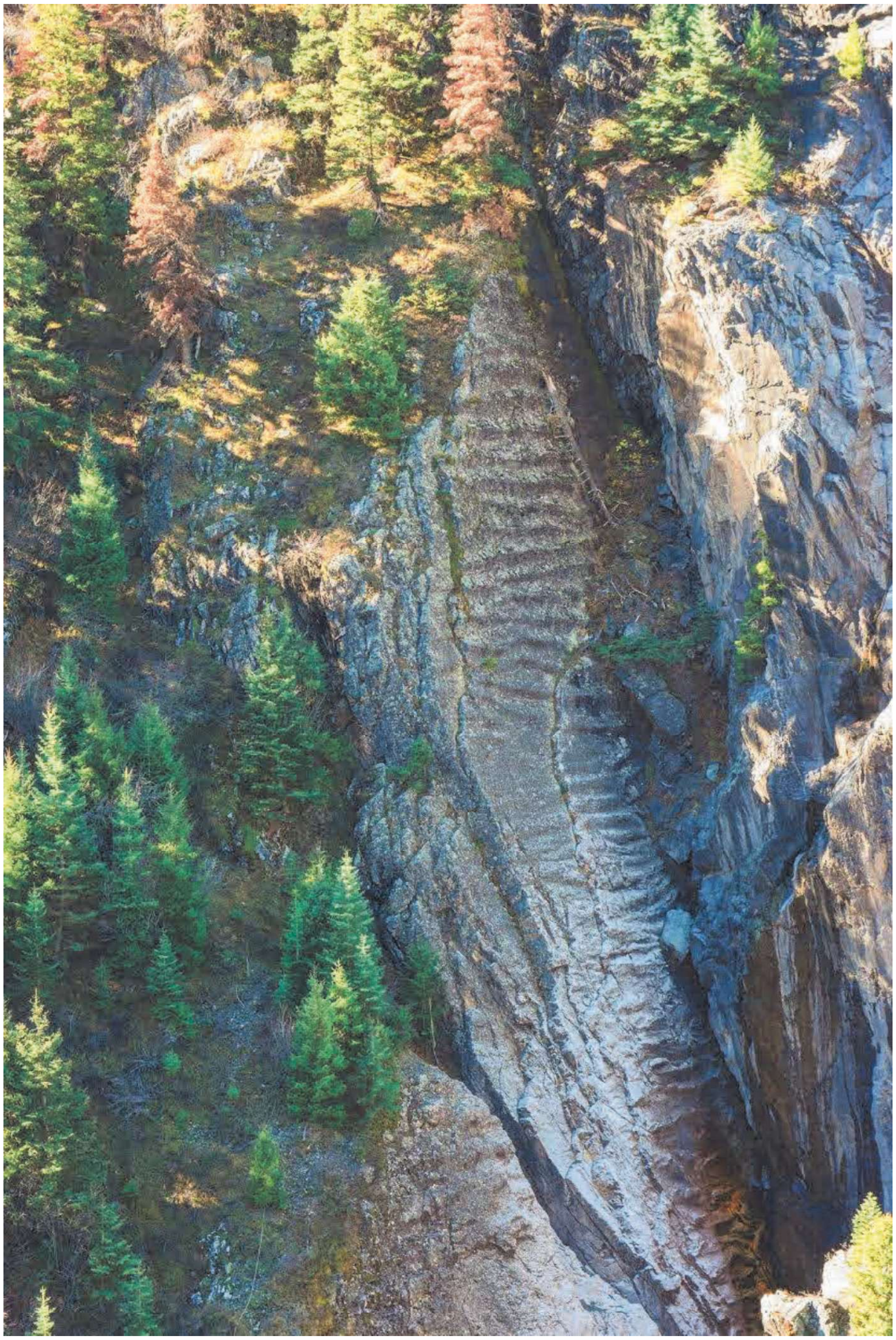


**Figure 14.** Subvertical bedding in the Uncompahgre Formation reveals primary sedimentary features such as cross bedding and ripple marks that tell the “younging” direction during deposition, and led Harris (1987, 1990) to interpret this succession as shallow marine in origin. Photograph is courtesy of Robert Powell.

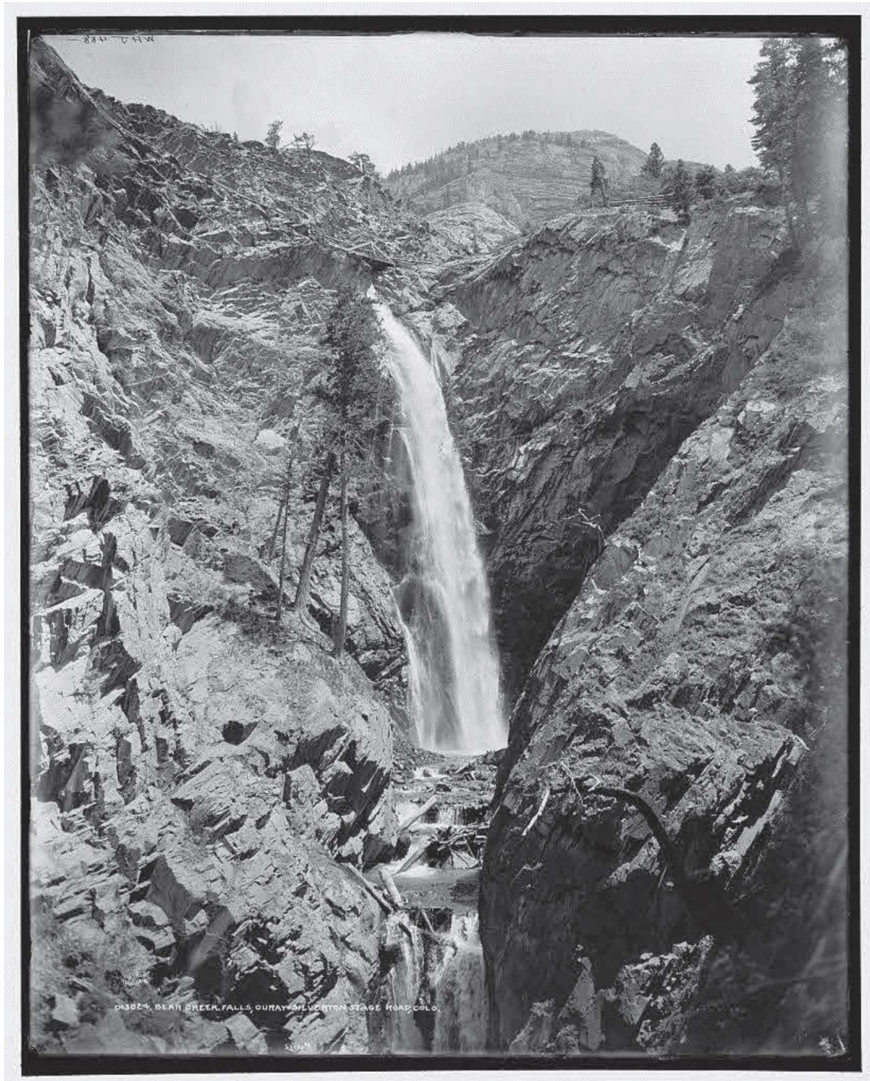



**Figure 15.** Photograph by W.H. Jackson of the Bear Creek Falls in 1901. Note the toll road at the top of the falls. Downloaded from the Library of Congress website.

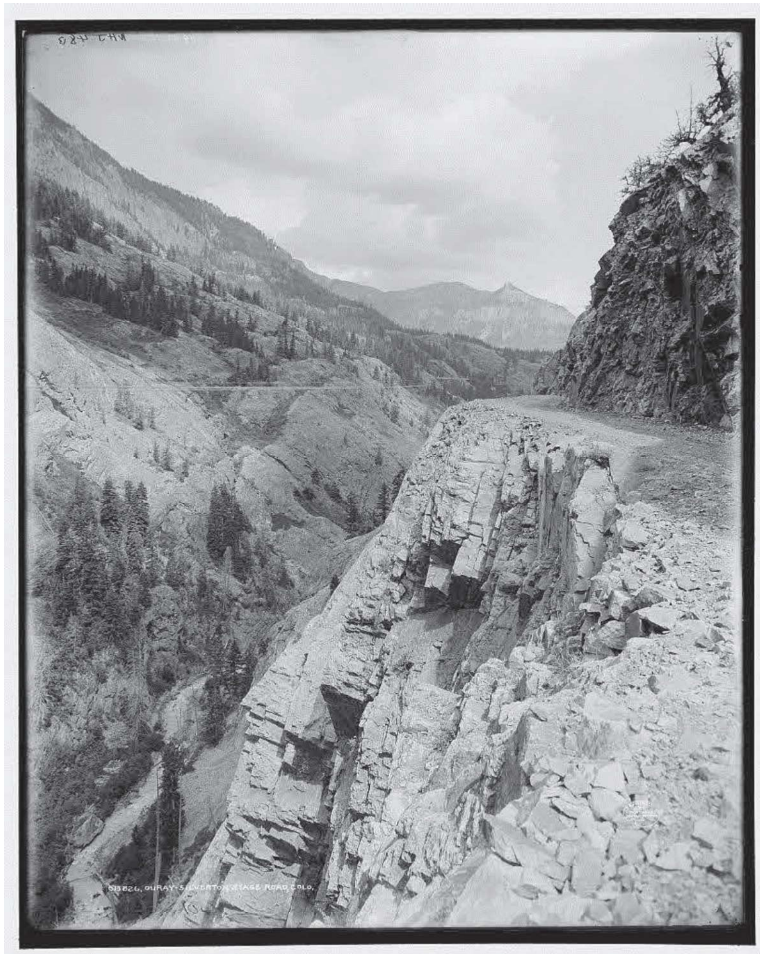


**Figure 16.** A section of the toll road between Ouray and Silverton around 1898 cut into Proterozoic Uncompahgre Formation. This road would become the Million Dollar Highway used today. The Twin Peaks, west of Ouray are visible in the distance. Photograph was obtained from the Library of Congress online collection.

**On HW 550N on just south of Bear Creek.**

The Sutton Mill (Fig. 17) once stood along Highway 550N south of Bear Creeks Falls. The mill was erected in 1926 but was burned down in the late 1970's. It processed ore from mines (Sutton and Hayden-Como) located on the steep canyon walls to the southwest in the San Juan Formation; the mines were connected to the mill by a tramway across the canyon. The mill also processed ore from mines in the Red Mountain district.

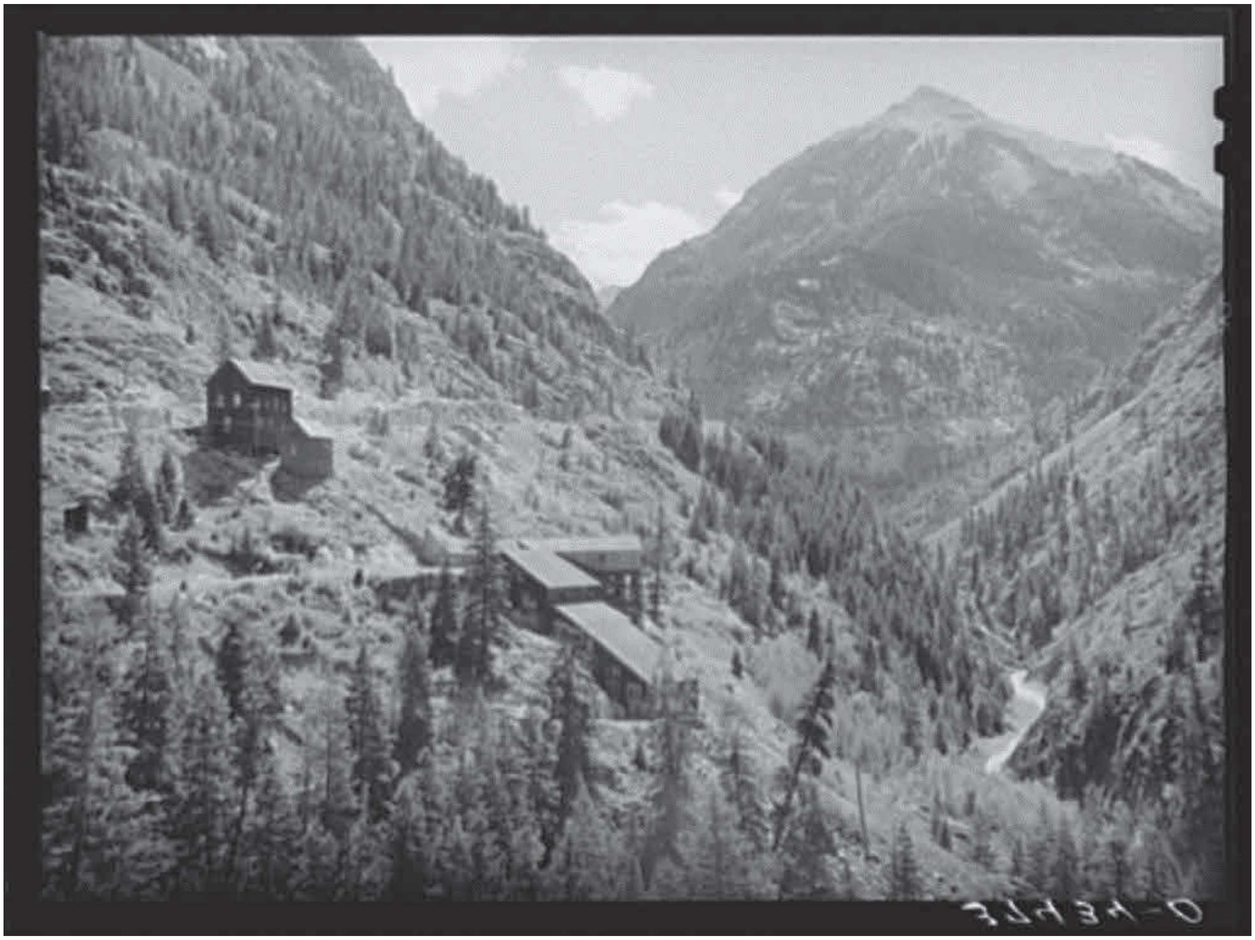


**Figure 17.** Photograph of the Sutton Mill near Bear Creek Falls. Photograph was taken by L. Russell in 1940. Abrams Peak looms in the distance to the south. Obtained from the digital collection of the Library of Congress.

Wonderful exposures of Uncompahgre Formation in the canyon. From this point to Ironton Park, on the west side of the canyon, there are glimpses of the “Great Unconformity” between the Uncompahgre Formation and San Juan Formation, a gap in time of about 1.65 billion years; nearly a quarter of Earth history is “missing” at this contact .

Watch for mountain goats on the steep cliffs.

**Junction with Engineer Mountain Road and the Alpine Loop Road, Climax Creek gorge.** The steep cliffs of Uncompahgre Formation in this area reveal a complex history of deformation with at least three different generations of folds (Fig. 18)

The steep cliffs just above the east side of the highway are the site of numerous avalanches on the Mother Cline slide path. The avalanche path was named after Mother Cline who ran a boarding house for miners in the area. On the west side of the canyon the “Great Unconformity” between the Uncompahgre Formation and San Juan Formation is visible.

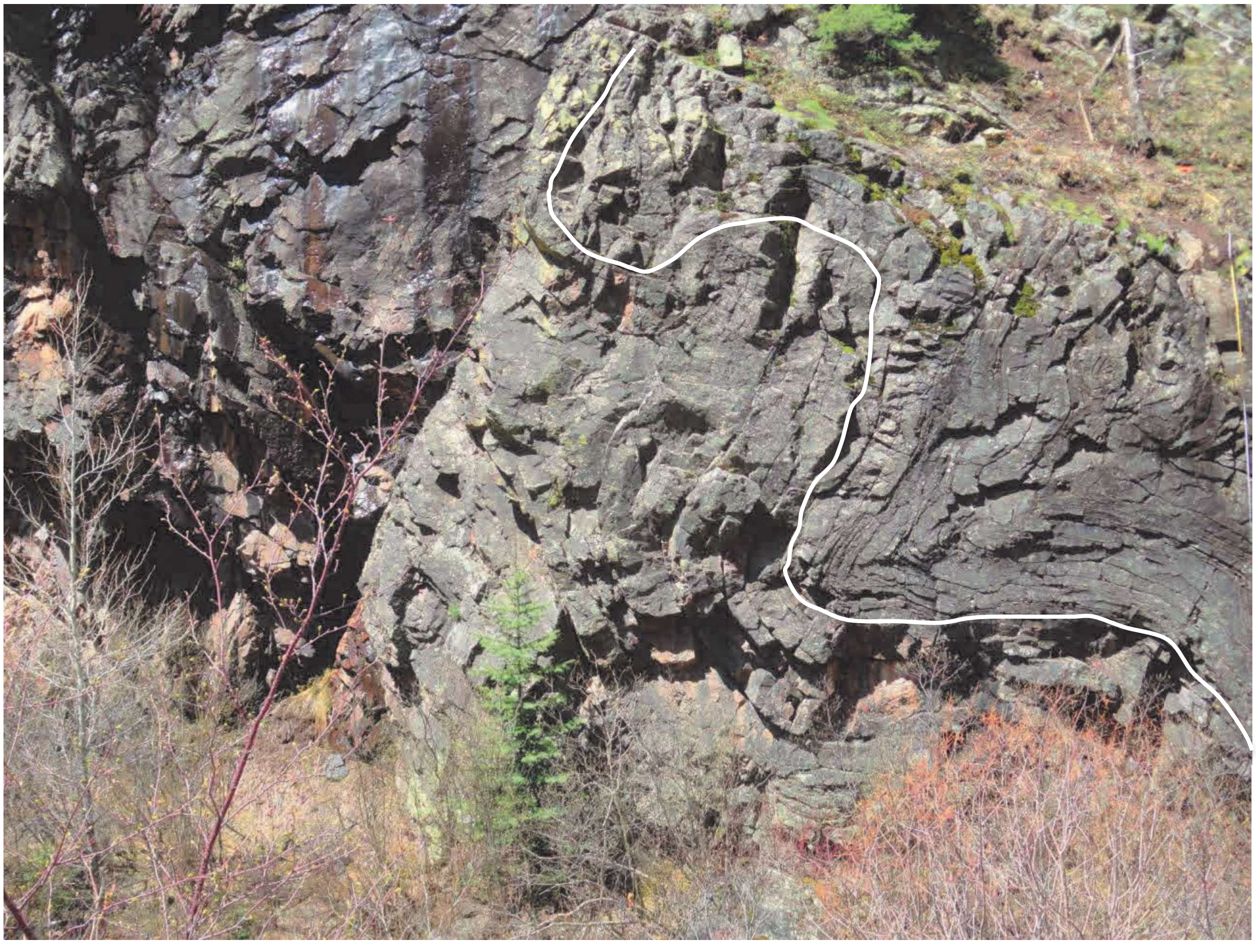


**Figure 18.** Deformation in the Uncompahgre Formation is best seen in the more ductile phyllite. At this location a beautiful subrecumbent F2 fold is exposed in the walls of the creek. Early F1 isoclinal folds are found in this outcrop that are then refolded by F2 and F3 generations. Deformation was probably progressive from one folding period to another as the strain field shifted during deformation.

**Drive back towards Ouray.  Take turn at Box Canyon Falls.  Bathroom stop.**

Drive to public parking area by CDOT.  Start hike to Box Canyon fall high bridge.

At this location, highly folded phyllite is exposed in north limb of the syncline mapped by Harris (187, 1990; designated P4) (Fig. 10).  The phyllite has a steep dipping northeast-foliation that is crenulated and folded.

Just west of the bridge over Uncompahgre Gorge in the road cut a diabase dike-sill cuts the quartzite.  The age of this dike is uncertain but is likely either ~1400 Ma or ~600 Ma.

From the trail there is a great view of the steep cliffs on the east side of Ouray.  The angular unconformity between the Permian Cutler Formation and Triassic Dolores Formation is revealed about midway up the hillside (Fig. 19).  The old workings and dump of the Chief Ouray mine are visible near the upper-middle part of the photo in the Cretaceous Dakota Sandstone.  To the north, the large orange-brown outcrops are located within and around The Blowout which is a granodiorite stock that was emplaced at 65.9 ± 1.1 Ma (Gonzales, 2015).  Disseminated pyrite and chalcopyrite are present throughout the stock.

**Figure 19.** View of the mountains east of Ouray. The "limonite" altered pluton of The Blowout is visible to the north (left), and the angular unconformity between the Paleozoic and Mesozoic section is identified with the white dashed line.

In the Uncompahgre Formation we will observe cross-stratification and graded bedding in quartzite. Bedding is near vertical and the direction of younging of the stratigraphic succession is to the south (top in these photos) as indicated by graded bedding, load features, and cross stratification (Fig. 20).

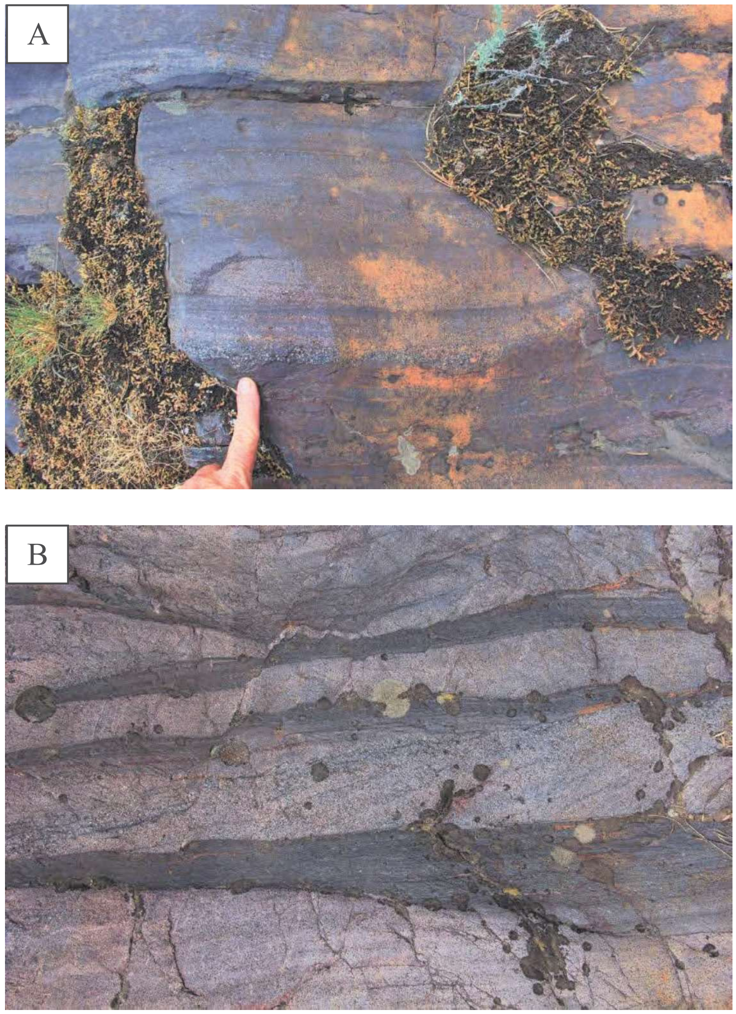



**Figure 20.** (A) Quartzite in the Uncompahgre Formation exhibiting cross stratification, load features, and graded bedding that record stratigraphic younging to the south (top of photos). Note small normal fault that dies out up and down section (in B) suggesting syn-sedimentary faulting.

**Footbridge over Canyon Creek.** This location affords a fantastic view of the angular unconformity between Proterozoic Uncompahgre Formation and the lower Paleozoic section (Figs. 21 and 22). The diabase dike that is well exposed to the east is exposed in the steep canyon walls about 50 feet north of the bridge and is covered by the sedimentary rocks. The east-west trending Ouray fault defines the steep northern wall of Box Canyon Falls.

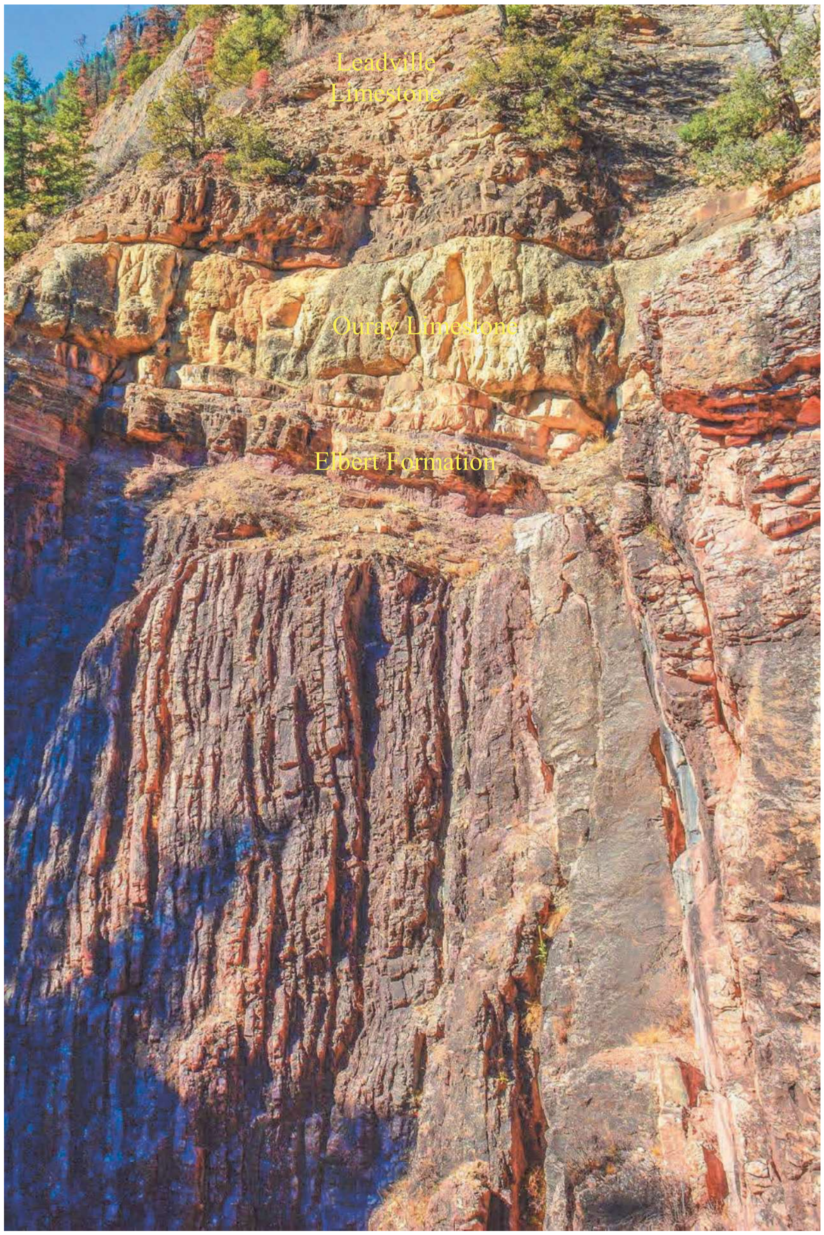



**Figure 21.** The "Great" angular unconformity developed between the near vertical layers of the Uncompahgre Formation and the gently dipping beds of the Devonian and Mississippian shale and limestone. Photograph courtesy of Robert Powell.

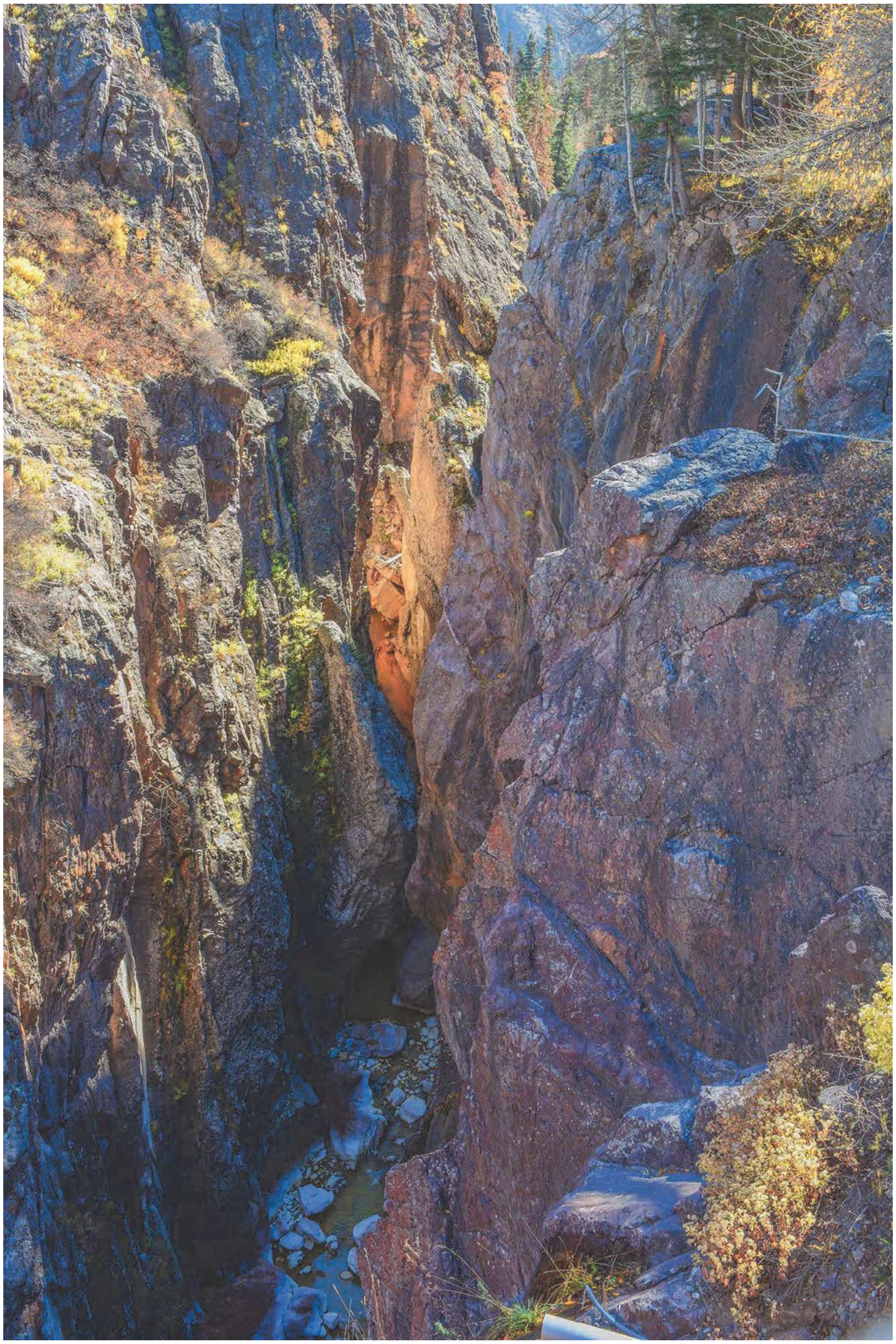


**Figure 22.** Steep gorge cut into the quartzite of the Uncompahgre Formation to the south of the foot bridge over Box Canyon Falls. Photograph courtesy of Robert Powell.

We will hike back to the vehicles and then to Box Canyon falls parking are for our lunch stop. The parking area is situated along the Ouray fault, which forms a steep wall in Canyon Creek where the Pennsylvanian Hermosa Group is down against the Uncompahgre Formation.

West of the visitor's hut there is a trail that leads to Box Canyon Falls in Canyon Creek. The creek has carved into the Uncompahgre Formation creating a large erosive "amphitheater" in which water rushes through the canyon. There are numerous rills and pot holes carved into the canyon walls.

### Drive to parking area near Portland Creek-Baby Pools

Start hiking from the parking area eastward towards Baby Bathtubs. Just west of the bridge over Portland Creek there are exposures of silicified Mississippian Molas Formation. The Molas represents a karst surface that developed on the Mississippian Leadville Limestone. At this location, there are good examples of collapse breccia, intraformational slumping and soft-sediment deformation. The rocks are cut by a set of north- to northwest-trending veinlets and fractures that are partially to entirely filled with quartz ± calcite ± sulfide minerals. Bleaching and silicification of the limestone breccia is evident adjacent to the veins. Burbank and Luedke (2008) argue that the fractures and veins are late Mesozoic in age.

As we cross the bridge over Portland Creek **(38.017865, -107.665513)**, note the distinct difference in the channel depth and morphology of the modern Portland Creek tributary to the Uncompahgre River. South of the bridge the creek channel is about 10 feet deep and has a more gentle gradient, but north of the bridge the canyon is narrow and about 100 feet deep with a steeper gradient. This abrupt change mimics similar knickpoints in the Uncompahgre River and its tributaries near Ouray, including Box Canyon itself, that have been attributed to a combination of hard bedrock of the Uncompahgre Formation, an incision transient related to post 10-Ma uplift of the San Juan Mountains, and/or incision of steep slot canyons during and following glacial times (Aslan et al., 2014).

Our hike on the trail on the east side of Portland Creek skirts the edge of landslide deposits in The Amphitheater. Subsequent to the final retreat of the glaciers, the scarp of The Amphitheater (Fig. 9) was subjected to considerable surface slumping and debris collapse that was caused by oversteepened slopes along the cirque basin.

Along the hike we will crossing Portland Creek. Note the fluvial-erosive sculpturing in the Leadville Limestone that has created numerous pools and rills.

**Drive from Baby Pools parking area to Cascade Falls Park.**

We will take a short (0.25 mile) hike from the parking area to the base of the falls.

This short hike provides an opportunity to view the Cascade Falls and examine the Pennsylvanian rocks of the Hermosa Group (Fig. 1). Cascade Falls is the last in a series of falls that have developed over cliffy exposures of the north-dipping Paleozoic and Mesozoic section in this area. Several fractures and minor faults cut the Hermosa Group on the slopes of Cascade Mountain north of Cascade Creek. The 1:12000-scale map of Burbank and Luedke (1981) shows several thin granodiorite dikes cutting the section on the trail.

**Lower Cascade Falls**

The lower part of the Hermosa Group is beautifully exposed at Cascade Falls on the east side of Ouray (Fig. 23). Sandstone, fossiliferous marine limestone, and shale are interbedded in the steep cliffs at this point. Fluvial erosion has created a series of overhangs in the cliff face. A trail near the bottom of the falls gives access behinds the waterfall on one such overhang.

Franczyk (1993) measured the entire Hermosa Group in Ouray in two sections, the lower one starting near Box Canyon Falls and the upper one starting at Cascade Falls. Based on her measured sections, the total thickness of the Hermosa in Ouray is 1000 feet.

During deposition of the Hermosa Group, the ancestral Uncompahgre uplift were a nearby source for the Hermosa clastic material. The Hermosa Group outcrops in the Ouray area are the most northern exposures and the most proximal to the Uncompahgre uplift of Pennsylvanian outcrops along the area that formed the southeastern margin of the Pennsylvanian Paradox Basin (Franczyk, 1993). The Hermosa Group is overlain by the Cutler Formation in most of the Ouray area, but in the area east of Cascade Falls pre-Triassic erosion has removed the Cutler so that the Hermosa is overlain by the Triassic Dolores Formation (Figs. 1, 2).

Gianniny and Miskell-Gearhardt (2009) proposed a sequence stratigraphic model to explain the depositional cycles in the Hermosa north of Durango.

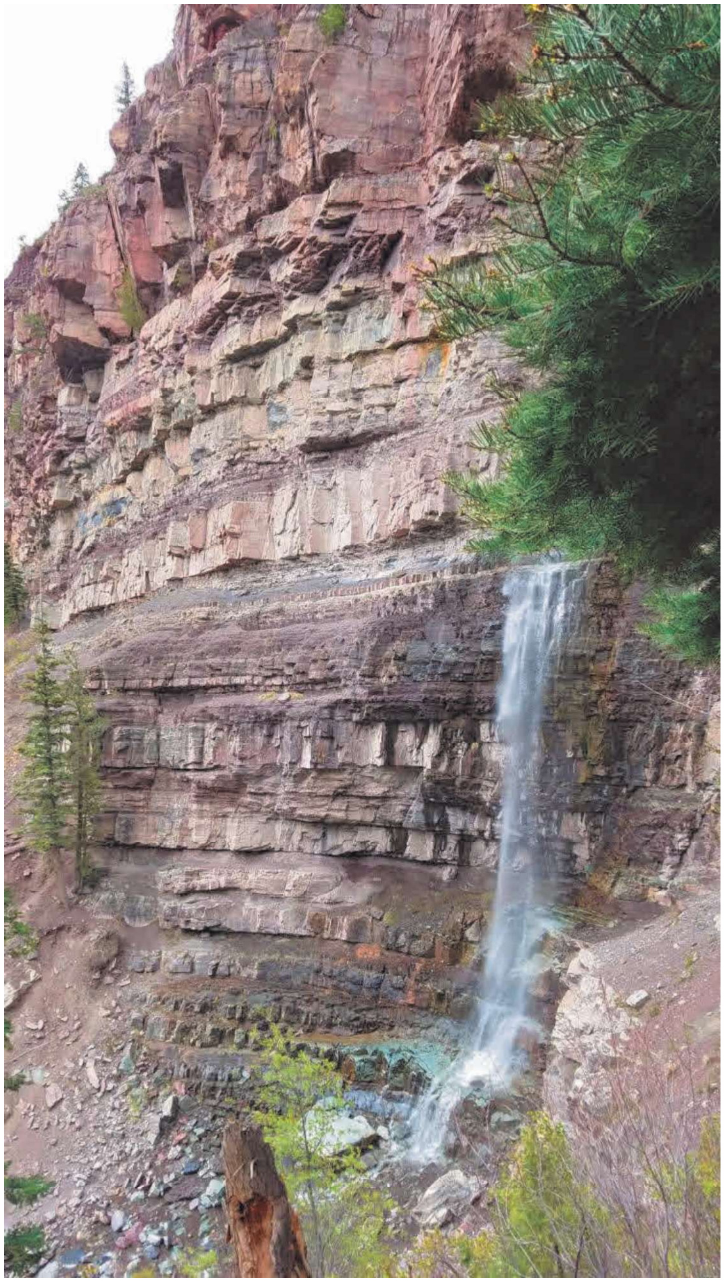


**Figure 23.** Exposed section of Hermosa Formation in the steep cliffs at Cascade Creek falls. Photograph courtesy of Steve Cumella.

**Drive from Cascade Falls Park to "dike" wall north of Ouray (30 minutes)**

We will drive north of Ouray to a section of BLM land north of Cutler Creek. We will park about 0.15 miles south of the area on the west side of the highway where there is a wider pullout.

At this location, the Triassic and Jurassic section is cut by a mafic dike (Fig. 24). Erosion of the sedimentary rocks has exposed the dike into a "wall" that is used by local climbers. The walls of the dike reveal complex structures that resemble pillowed lava, and could indicate that the dike encountered groundwater in the surrounding rocks during emplacement. The mafic composition of the dike is rather rare in the Ouray area. Augite and plagioclase are the dominant constituents. An argon age analysis on the groundmass revealed an age of ~14 Ma which is similar to a diorite-granodiorite dike found in Disappointment Valley to the west, but otherwise, mafic rocks of this age are not common in the region. Aphanitic to porphyritic-aphanitic granites such as the sill exposed at Engineer Mountain are dominant rock types of the 14 Ma clan.

The Triassic Dolores Formation, and Jurassic Entrada Sandstone and Wanakah Formation are well exposed on the north-dipping section exposed in this area on the southern edge of a series of faults that define the Orvis block (Figs. 1, 25-26).

In terms of mining lore, the basal Pony Express Limestone Member of the Wanakah Formation (named for the Wanakah mine north of Ouray) is one of the most famous unit. There are many locations in the western San Juan Mountains where ore-bearing fluids interacted with the limestone creating replacement type deposits (Burbank and Luedke, 2008). The Pony Express Limestone is the equivalent of the Todilto Limestone in the San Juan Basin. In most outcrops in the Ouray area it is 10-20 feet thick and typically consists of two parts: a lower black petroliferous calcareous shale and an upper petroliferous brecciated vuggy limestone (Fig. 27). In a few localities north of Ouray, Burbank and Luedke (2008) report a much thicker section (~60 feet) that has an upper shaly mudstone containing gypsum nodules (Fig. 28).

At our stop, the Pony Express Limestone is less than 10 feet thick and composed mostly of a breccia composed of lenticular fragments of limestone. Luedke and Burbank (2008) concluded that the breccia (Fig. 28) resulted from dissolution of gypsum nodules by groundwater which caused layers of mudstone to break into fragments and plates which were recemented. They suggested that the dissolution took place in the Jurassic since the uppermost part of the Wanakah Formation and lower part of the Morrison Formation are thinned and arched over gypsum-bearing zones.

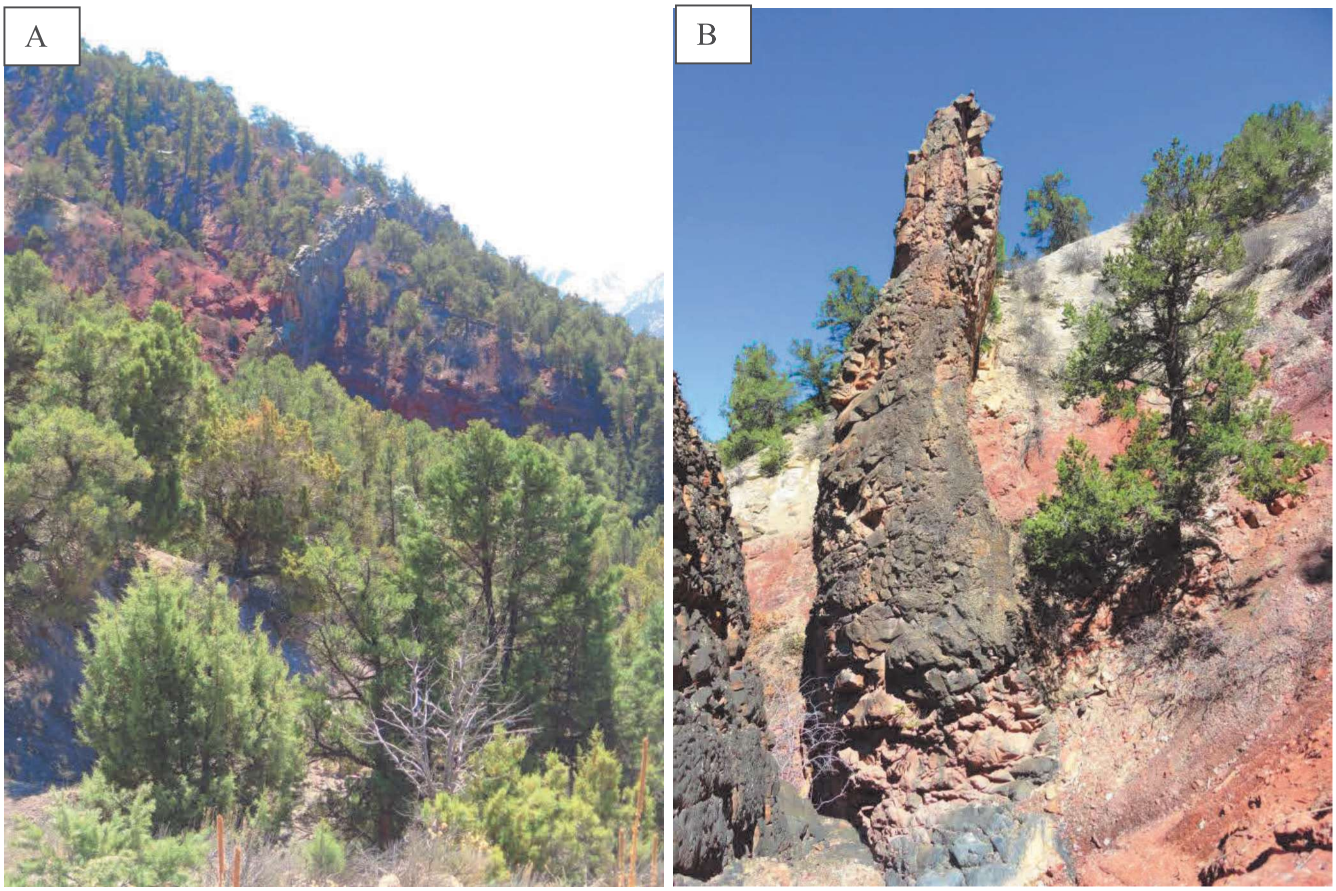



**Figure 24.** Diabase dike exposed at the “dike” wall. This dike is composed mostly of augite and calcic plagioclase with an ophitic relationship. An argon age analysis on the groundmass of this rock yield a preliminary time of emplacement of 14.5 Ma (personal communication with Dr. Matt Heizler, March 2017). (A) Distal view of the dike looking south towards Ouray; (B) Closer view of the dike showing the complex structures developed on the margins.

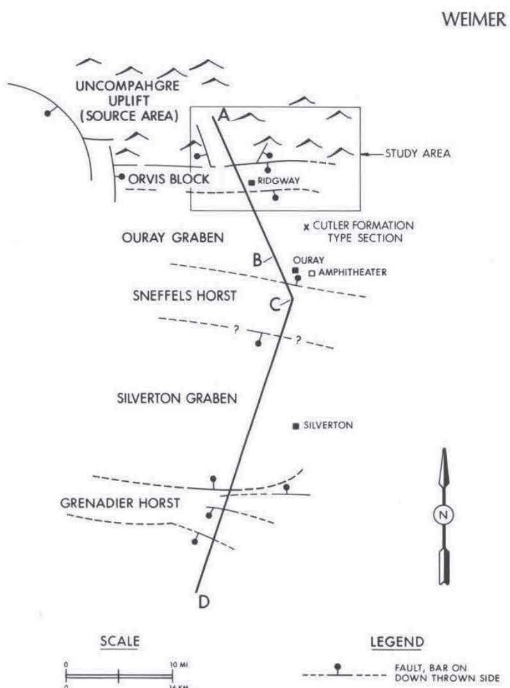



**Figure 25.** Generalized map of the structural elements between Ouray and Ridgway with a regional north-south section (taken from Weimer, 1981)

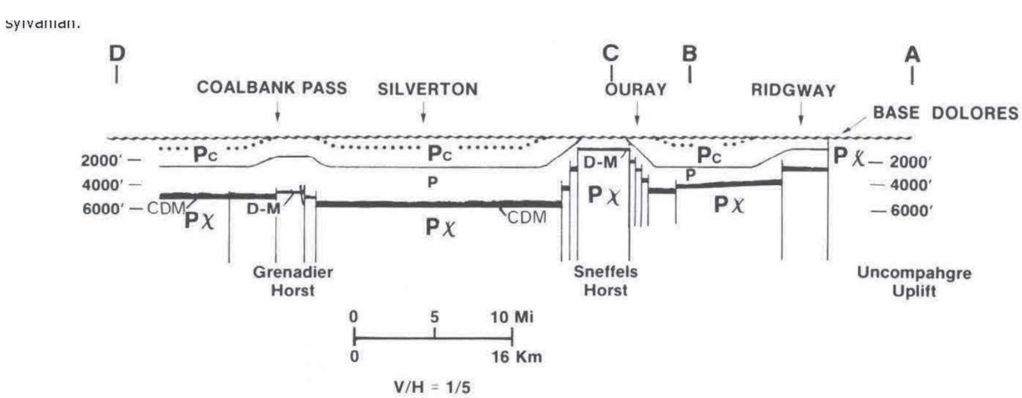



**Figure 26.** Regional cross section restored to the base of the Dolores Formation showing dominant host and graben blocks (taken from Weimer, 1981). The letters correspond to those shown on Figure 25.

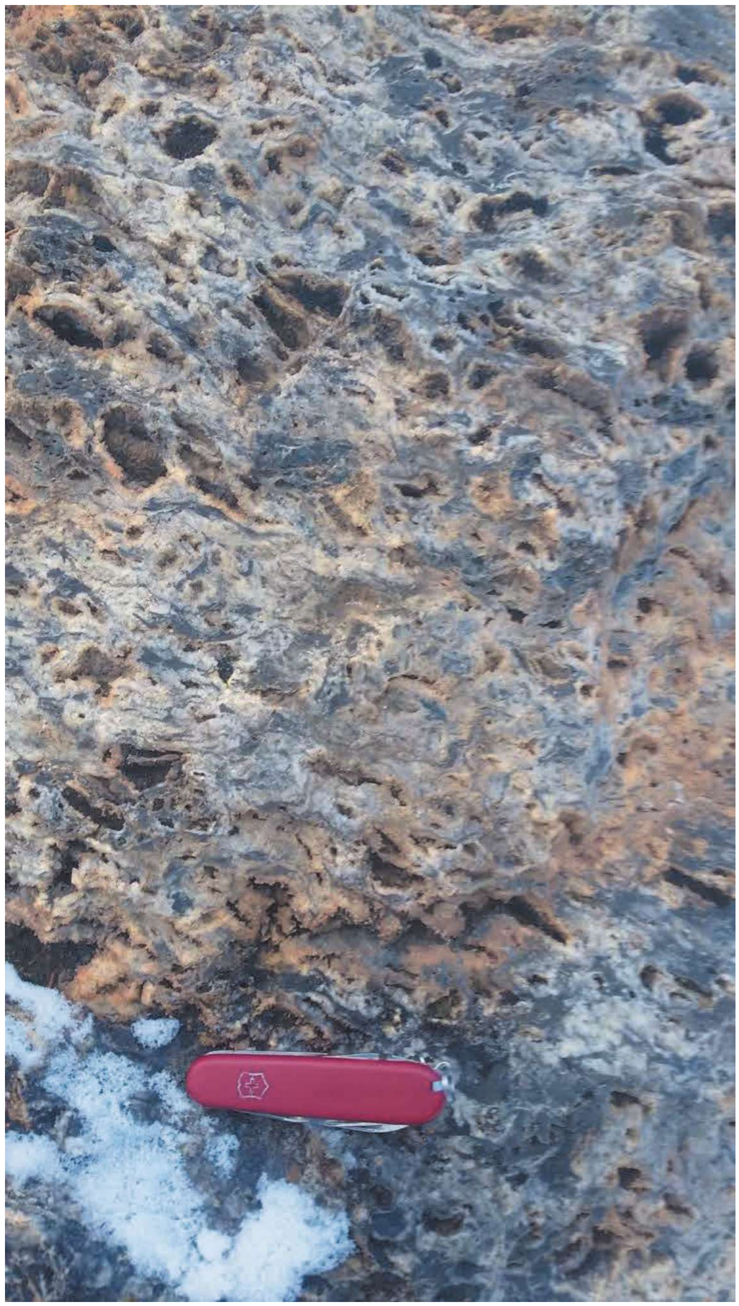


**Figure 27.** Upper petroliferous brecciated vuggy limestone of the Pony Express Limestone (photo provided by Steve Cumella).

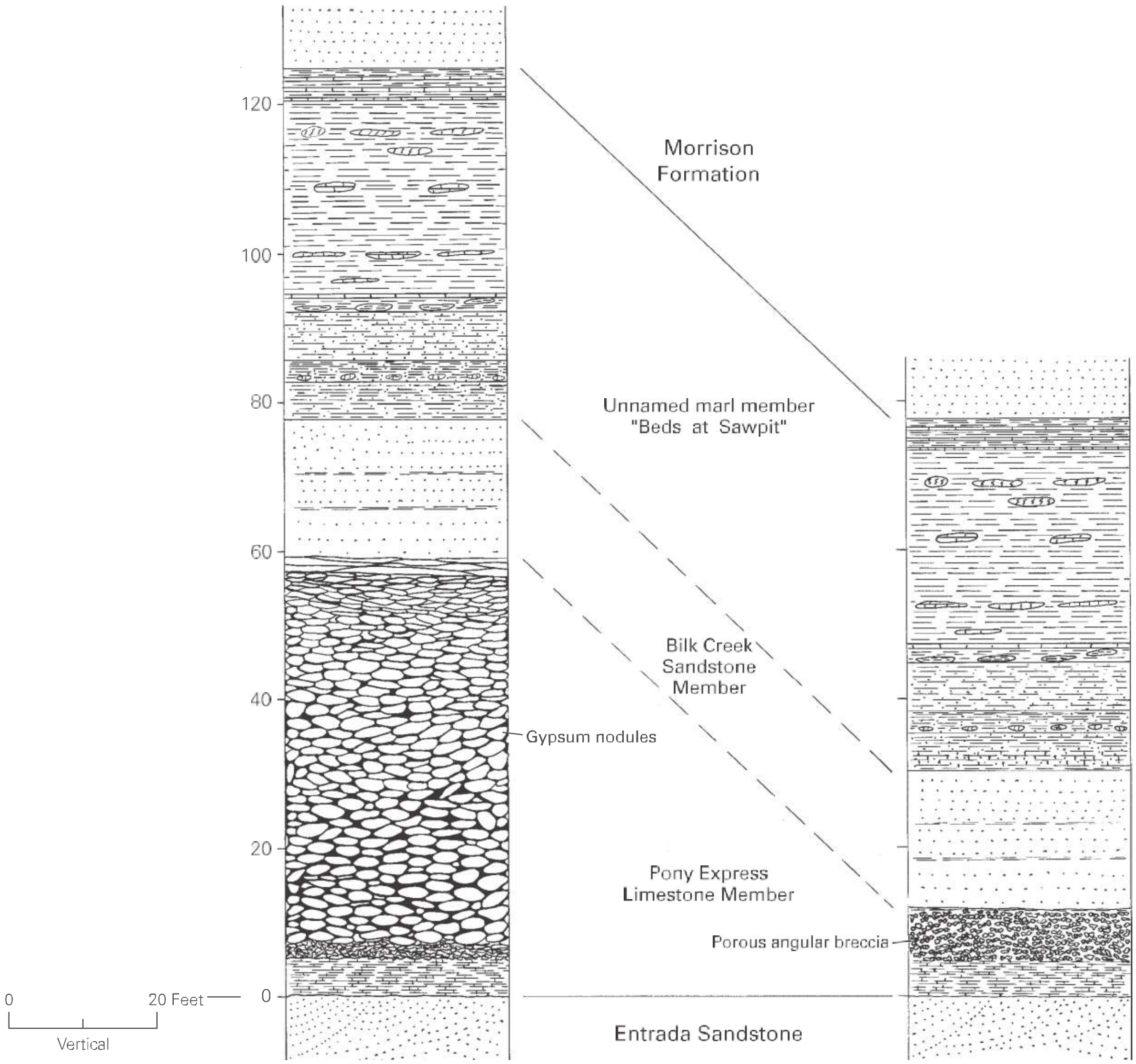



**Figure 28.** Generalized sections of Wanakah Formation on the east side of the Uncompahgre River canyon about 1.5 miles north of the mining district in the vicinity of Ouray. The thicker section contains gypsum nodules separated by mudstone. The gypsum was later dissolved by groundwater that caused collapse and brecciation of calcareous mudstone (taken from Burbank and Luedke, 2008).

**GEOLOGY ALONG THE OURAY AREA**
**June 1-2, 2019**

DAVID A. GONZALES AND STEVE CUMELLA

## Day 2 Logistics

Day 2 of will explore more of the Paleozoic to Mesozoic stratigraphy, along with discussion on the late Mesozoic to Cenozoic magmatic history and formation of clastic dikes. We will also make a stop to examine replacement mineralization in the Pony Express Limestone.

**Meet at the Ouray Hot Springs parking area at 8:00 am, get organized to leave at 8:15 am.**

8:15 AM - 8:45 AM – Drive north of Ouray to CR 14 and then CR 14A to Cutler Creek.
8:45 AM - 10:15 AM – Discuss Permian to Cretaceous section, mineralization in Pony Express.
10:15 AM – 10:45 AM – Drive to pull off on HW550N several mile north of Ouray.
10:45 AM – 12:00 AM – Overview of post-66 Ma magmatic history, altered brecciated dike.
12:00 PM – 12:15 PM – Drive to Rotary Park a mile north of Ouray.
12:15 PM – 1:15 PM – Lunch.
1:15 PM - 2:00 PM – Discussion of Cutler Formation and clastic dikes.
2:00 PM - 2:30 PM – Drive to Box Canyon Falls turn off, drive to start of hike to Angel Creek
2:00 PM - 3:00 PM- Hike to Angel Creek.
3:00 PM -4:00 PM- Discuss magmatic to clastic dike history, Hermosa Formation.
4:00 PM – 4:30 PM – Hike back to vehicles, end of trip.

**Departure time:** Vans and some personal cars will leave from the Ouray Hot Springs parking lot at 8:15 AM.

**Travel Logistics:** The Day-2 trip will drive in personal vehicles and start and end in Ouray.

**Stops:** Short to moderate hikes are planned at each stop. Driving times between stops vary from as little as 15 minutes to as much as 30 minutes. Please plan accordingly. Restroom facilities are limited outside the town of Ouray.

**Drive from Ouray Hot Springs to CR14. We will drive past Lake Lenore (2.7 miles) and continue to the junction of CR14 and CR14a. Another ~1.5 miles will bring us to our parking destination at the junction of CR14a and CR 14b.**

From the parking area will are going to do a slow hike along the road for about 0.7 miles. This hike will take us past the Newsboy mine (Burbank and Luedke, 2008, Plate 6) and Senorita mine (Burbank and Luedke, 2008, Plate 7). A good overview of both of these mines can be found on pages 100-103 of the Burbank and Luedke (2008). Although these mines were by no means the most productive or well known in the Ouray district, they do offer excellent examples of the interaction of plutons, ore fluids migrating in fractures, and strata that caused precipitation of mineral deposits. These two mines produced nominal amounts of silver in argentiferous galena, tetrahedrite and minor polybasite ($Ag_9CuS_4Ag_4Cu_2Sb_{1.25}As_{0.75}S_7$) and pearceite ($Ag_{12.15}Cu_{3.84}As_{1.18}Sb_{0.83}S_{11}$). Dominant gangue minerals are quartz, sericite, ankerite, and barite. Deposits at both mines formed along fractures trending ~N80˚E with mostly steep dips from 65˚ north to 90˚ though fractures

The Newsboy vein system is on strike with a felsic dike that is exposed in the Cutler Formation to the west. The most productive zones in the mines extended from the Entrada Sandstone to the lower part of the Morrison Formation. Mineralization appears to have been mostly controlled by fractures and breccia zones developed in more competent units, and replacement-type deposits (i.e., mantos) in the Pony Express Limestone (Burbank and Luedke, 2008, Plate 7). A. Good examples of replacement ore are found in blocks of rock on the road we will be hiking.

The view west across the valley provides a beautiful view of the sedimentary section from the Cutler through the Mancos showing regional dip towards the north (Fig. 29). There is an interesting dip reversal north of Cutler Creek where beds dip to the south (Fig. 30). The south dip continues to near Dexter Creek where it reverts back to north dip. The dip reversal is present in Cutler through Dakota strata, but more pronounced in the Cutler, suggesting recurrent movement of basement structure.

The end of our hike will give us a fantastic view of Cutler Canyon, exposing the section from the Permian into the late Cretaceous. Cutler Creek is the type locality of the Cutler Formation.

**Drive back towards Ouray. At US HW550N we will turn right (north) and drive less than a mile. We will park on the east side of the highway to avoid crossing it. Be watchful of traffic.**

At this stop we are going to examine an example of a clan of altered dikes in the area (Fig. 31). Luedke and Burbank (1962) mapped several dikes and small masses of altered granodiorite to diorite (unit Pa) in the vicinity of Ouray that are in close spatial relationship with the clastic dikes. In some outcrops, the granodiorite dikes and adjacent country rock exhibit fragmentation and brecciation (Fig. 32) from the release of magmatic volatiles during emplacement. Near Lake Lenore a small mass of this altered rock is reported to contain numerous sedimentary inclusions (Burbank and Luedke, 2008). Some of these intrusive rocks exhibit a microporphyritic texture defined by extremely altered feldspar in a fine-grained groundmass of felty feldspar and quartz. There is a high degree of alteration in the rocks related to deuteric fluids defined by sericite +

calcite + chlorite + Fe oxides pseudomorphs of feldspar ± hornblende ± biotite. Burbank and Luedke (2008) also report sulfide minerals in these dikes.

An altered granodiorite dike is also exposed about 100 feet west of the clastic dike in Angel Creek is part of this clan of intrusive rocks, and similar altered (quartz, kaolin, sericite, and hematite) and sheared "pebble" dikes are documented by Kelly and Silver (1946) in Silver Gulch about 10 miles south of Ouray. These "pebble" dikes tend into two mineralized breccia pipes. These altered plutons appear to be transitional phases between unfragmented graniodiorite dikes and the clastic dikes.

**Figure 29.** View of the Uncompahgre Valley west of Cutler Creek. Photography by Steve Cumella.

**Figure 30.** View of hillside north of Cutler Creek. Red strata in lower part of hillside are in the Cutler Formation; yellow line traces bed in upper Cutler. White line shows the unconformity at the base of the Triassic. Note the dip reversal at Cutler Creek. Photo by Steve Cumella.

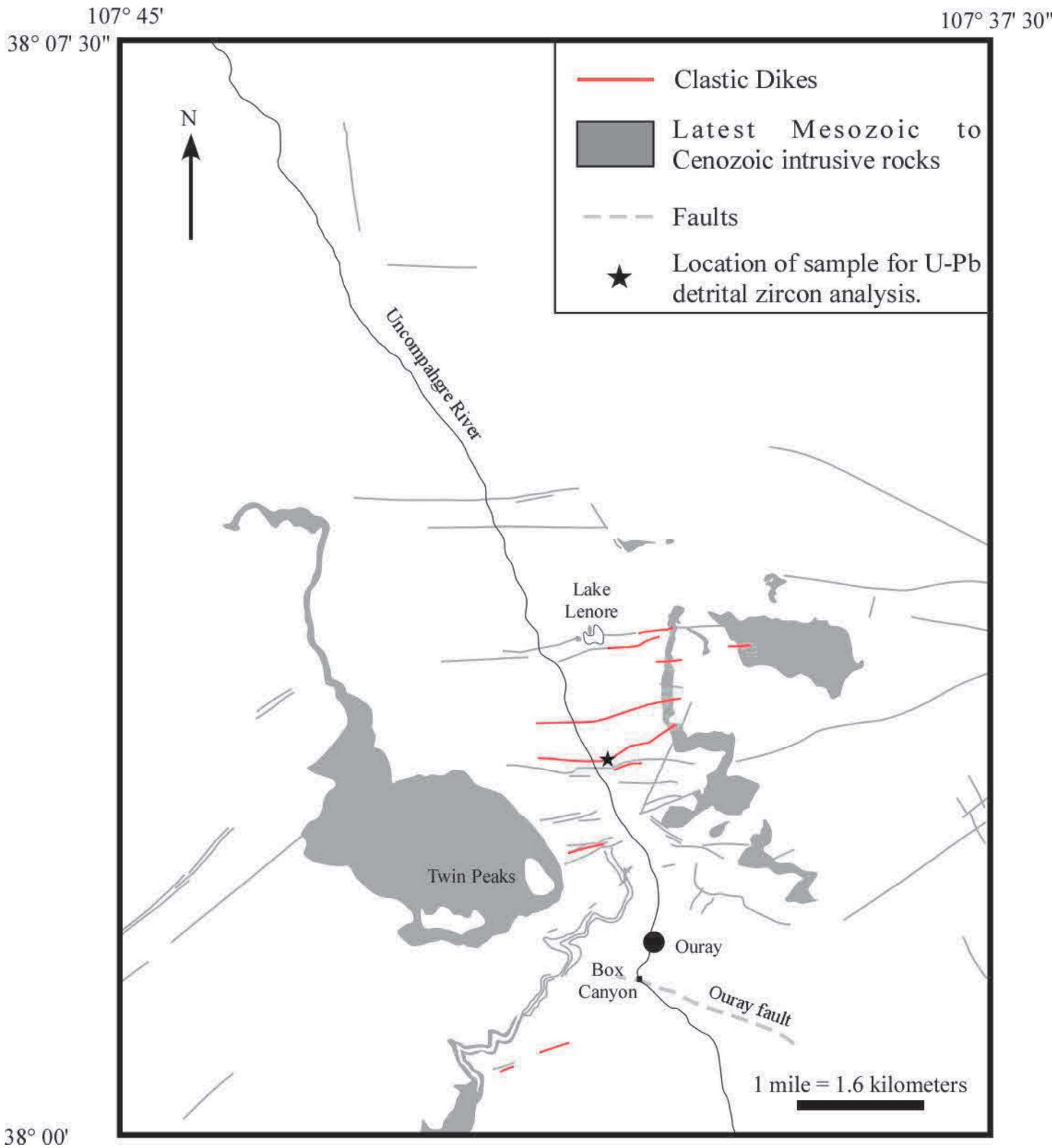



**Figure 31**. General geology in vicinity of Ouray showing the relationship of clastic dikes to latest Mesozoic to Cenozoic plutons, and faults. Light gray lines represent dikes and sills. The area colored white on the figure is undivided Paleozoic to Cenozoic sedimentary, and Cenozoic volcanic rocks. Modified after Burbank and Luedke (2008). The sample for U-Pb analyses was obtained from a cliffy outcrop at location 38.042852°N, 107.67946W.

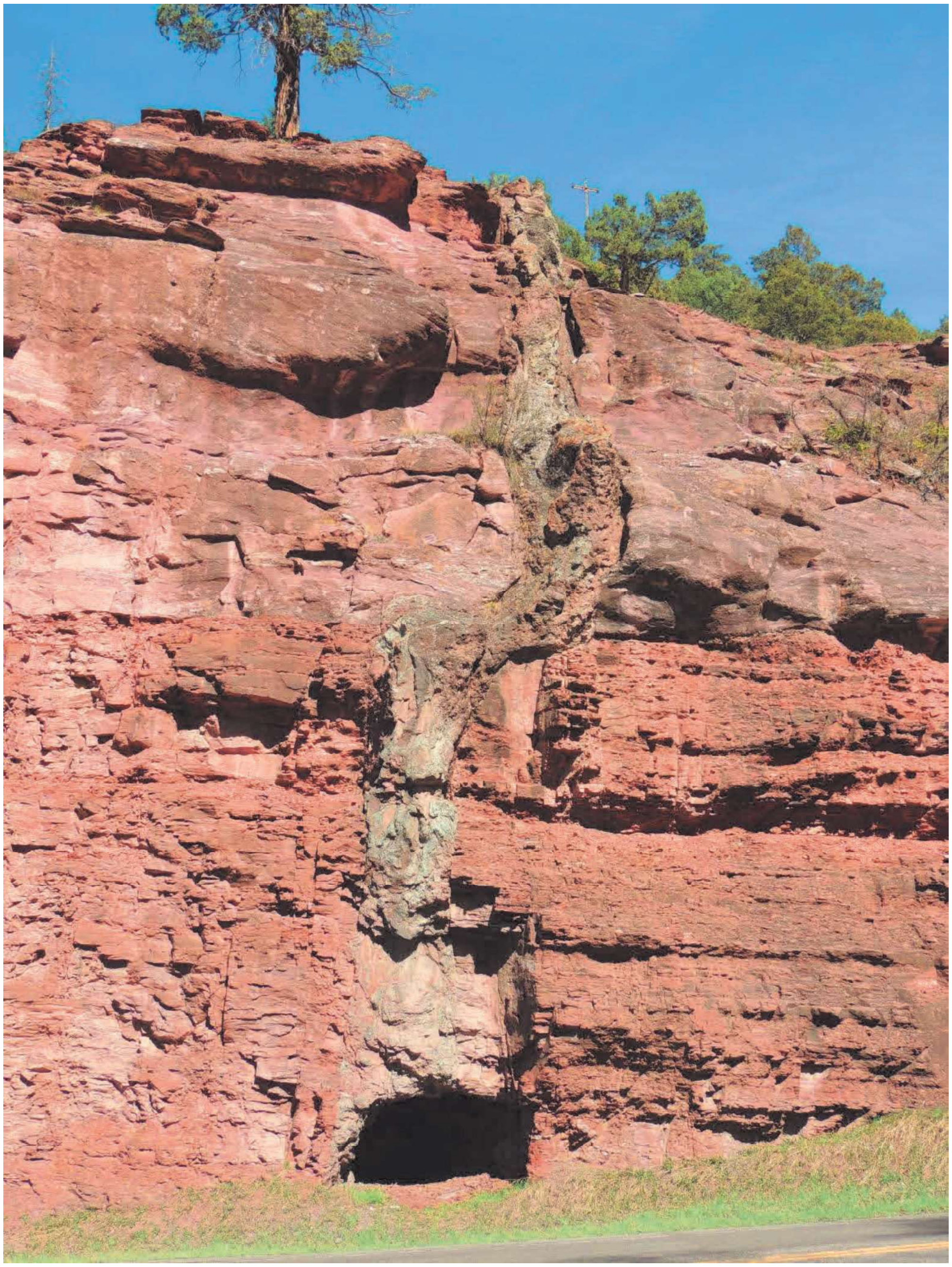
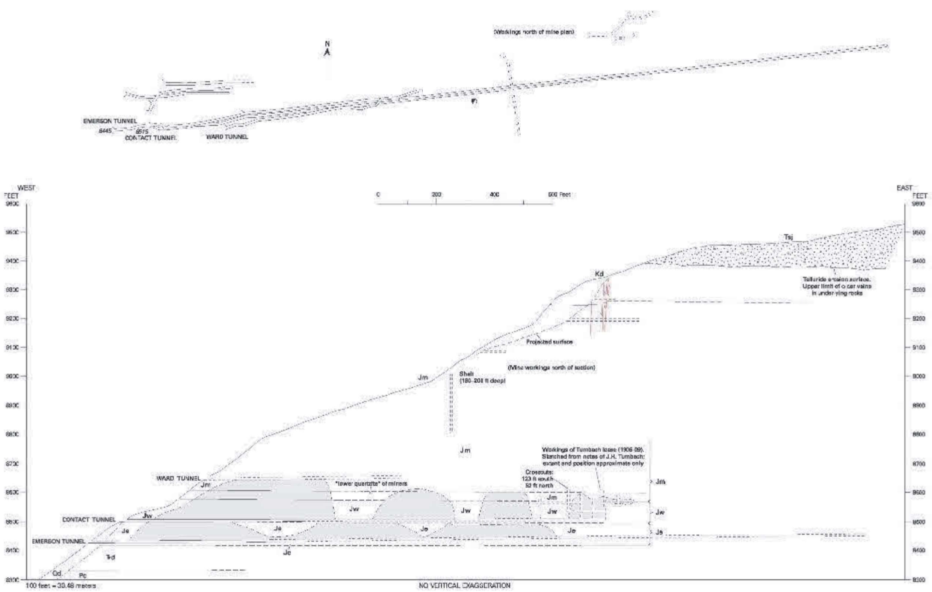
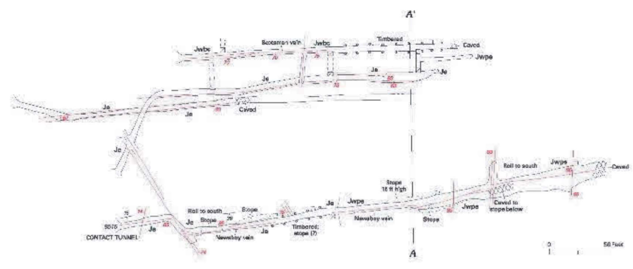


**Figure 32.** Highly altered and brecciated granodiorite dike exposed in the Cutler Formation west of Lake Lenore about 5 miles north of Ouray. Quartz and highly altered feldspar phenocrysts are set in a very fine-grained groundmass that is altered almost entirely to sericite, clays, and calcite. The dike contains fragments of the siltstone, and is also highly brecciated into subangular to angular fragments up to 15 cm in maximum dimension. The internal brecciation in the dike and alteration are indicative of high volatile content during emplacement. The short tunnel at the base of the dike is an old prospect. The photo is courtesy of Steve Cumella.

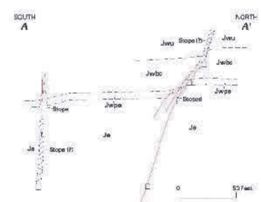
**Figure 33.** Normal fault with displacement to the north in the Cutler Formation about 100 feet south of Figure 30. The fault zone contains greenish altered material that might also be altered dike (photo courtesy of Steve Cumella).




Generalized mine plan and generalized longitudinal section




Enlarged plan map of western part of mine workings




Generalized section along A–A'

## EXPLANATION

[To correlate map units, refer to Correlation of Map Units on plate 1]

### MAP UNITS

| | |
|---|---|
| Qd | **Glacial drift (Pleistocene)** |
| Tsj | **San Juan Formation (Oligocene)** |
| Kd | **Dakota Sandstone (Upper and Lower(?) Cretaceous)** |
| Jm | **Morrison Formation (Upper Jurassic)** |
| | **Wanakah Formation (Middle Jurassic)** |
| Jwu | Upper unnamed member ("Beds at Sawpit") |
| Jwbc | Bilk Creek Sandstone Member |
| Jwpe | Pony Express Limestone Member |
| Je | **Entrada Sandstone (Middle Jurassic)** |
| Td | **Dolores Formation (Upper Triassic)** |
| Pc | **Cutler Formation (Lower Permian)** |

### MAP SYMBOLS

**Contact**—Dashed where projected

**Vein, mineralized fracture, or minor fault**—Showing inclined dip; dip not shown where vertical. Arrows indicate relative movement (shown in longitudinal section only)

**Strike and dip of inclined beds**

**Mine workings**—Showing portal. Dashed where projected

**Section view of crosscutting tunnel**

**Vertical shaft**

**Raise or foot of winze**

**Winze or head of raise**

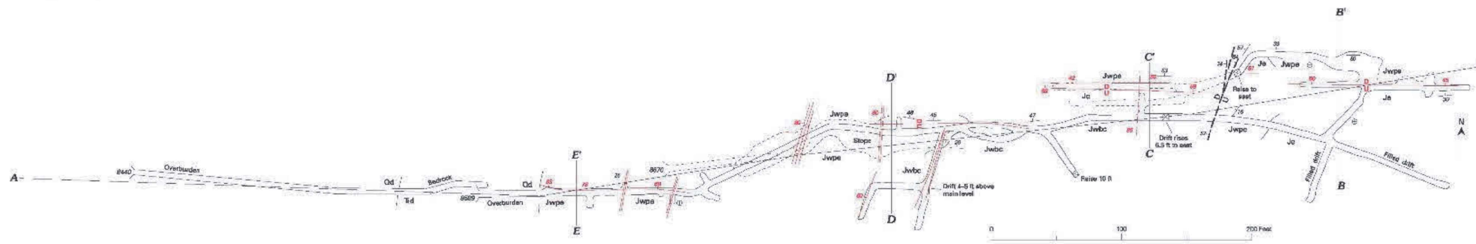
**Ore chute**

**Altitude, in feet**

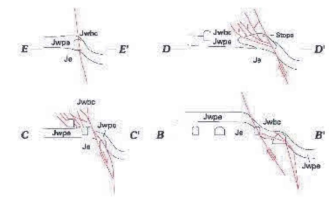
**Stoped area in longitudinal section**

Mine workings compiled from various source maps; altitudes adjusted to U.S. Geological Survey approximate altitudes of tunnel portals. Approximate courses and altitudes of some mine workings determined by alidade and plane-table surveys.

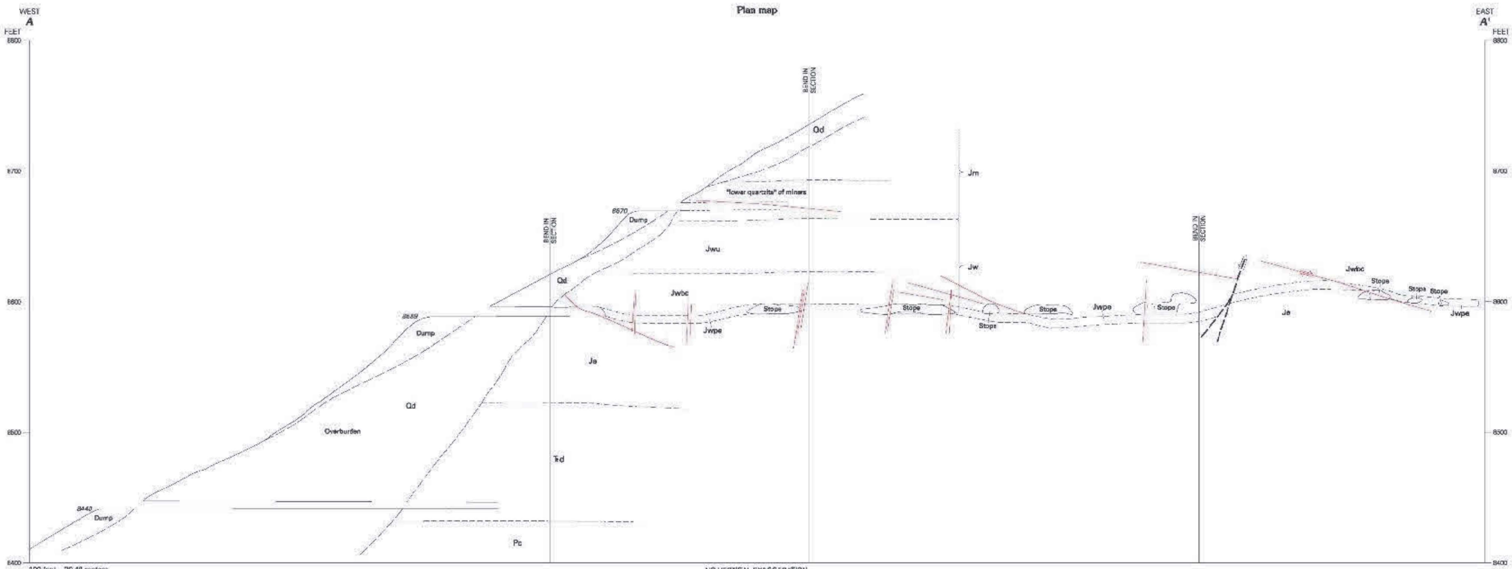
# PLAN MAPS AND SECTIONS OF THE NEWSBOY MINE, UNCOMPAHGRE MINING DISTRICT, OURAY COUNTY, COLORADO




Plan map




Cross sections (viewed looking west toward portal)




Longitudinal section showing mine workings and geology projected into line A–A'

## EXPLANATION

[To correlate map units, refer to Correlation of Map Units on plate 1]

### MAP UNITS

- Qd — **Glacial drift (Pleistocene)**
- Jm — **Morrison Formation (Upper Jurassic)**
- **Wanakah Formation (Middle Jurassic)**
  - Jwu — Upper unnamed member ("Beds at Sewpit")
  - Jwbc — Bilk Creek Sandstone Member
  - Jwpe — Pony Express Limestone Member
- Je — **Entrada Sandstone (Middle Jurassic)**
- TRd — **Dolores Formation (Upper Triassic)**
- Pc — **Cutler Formation (Lower Permian)**

### MAP SYMBOLS

- **Contact**—Dashed where projected
- 60 U D — **Vein, mineralized fracture, or minor fault**—Showing inclined dip; dip not shown where vertical. U, upthrown side; D, downthrown side. Arrows indicate relative movement (shown in sections only)
- 74 D U — **Fault**—Showing dip. U, upthrown side; D, downthrown side. Arrows indicate relative movement (shown in longitudinal section only)
- **Strike and dip of beds**
  - 8 — Inclined
  - Horizontal
- **Mine workings**
  - Plan view—Showing portal. Dashed where projected
  - Longitudinal section view—Showing portal. Dashed where projected
  - Section view—Crosscutting tunnel or drift; dashed in longitudinal section
- **Raise**
- 8765 — **Altitude, in feet**

Mine workings compiled from various source maps; altitudes adjusted to U.S. Geological Survey approximate altitudes of tunnel portals. Approximate courses and altitudes of some mine workings determined by alidade and plane-table surveys.

# PLAN MAP AND SECTIONS OF THE SEÑORITA MINE, UNCOMPAHGRE MINING DISTRICT, OURAY COUNTY, COLORADO

8

**Drive back towards Rotary Park north of Ouray for lunch.**

At our lunch stop we will have a fantastic view of steep, exposed walls of the Cutler Formation (Fig. 34). This is also where will start a discussion on the clastic dikes in the area. A great example of a clastic dike with abundant pebble- to cobble sized-fragments is exposed about 100 feet above the park. For those interested, we can do a short scramble to the outcrop.

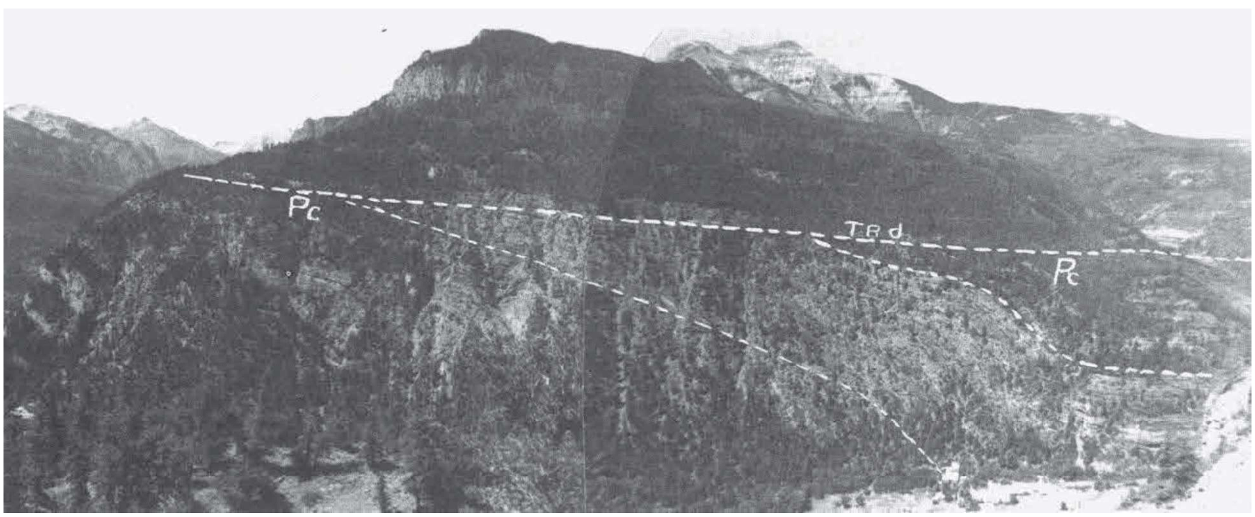



**Figure 34.** View of the west wall of the Uncompahgre River near Rotary Park showing paleodrape fold in the Cutler (Pc) and the base Triassic unconformity (Trd) (taken from Weimer, 1980).

North of Ouray, west- to southwest-trending clastic dikes (Luedke and Burbank, 1962; Luedke and Burbank, 1981) are exposed in Permian to Cretaceous sedimentary rocks (Fig. 31). The dikes are often in close proximity to ~66 Ma (Gonzales, 2015) granodiorite plutons. In several locations the clastic and graniodiorite dikes are adjacent or transitional on trend; locally clastic dikes crosscut and stope granodiorite plutons (Burbank and Luedke, 2008) (Fig. 31). Previous mapping (Luedke and Burbank, 1962; Luedke and Burbank, 1981) showed that clastic dikes do not extend into the Oligocene San Juan Formation demonstrating that they were emplaced between 66 and 30 Ma (Burbank and Luedke, 2008; Gonzales, 2015).

Ransome (1901) and Kushner (1973) noted that some of these clastic dikes north of Ouray are closely allied with some zones of mineralization, such as the upper workings of the Bachelor mine. Rich deposits of Ag-Pb-Zn-Cu were developed on the Bachelor "dike" that developed in a fracture system that trend of ~N80 E (summarized by Burbank and Luedke, 2008) (Fig. 35). Evidence argued that the dike preceded mineralization and created open space for mineralizing fluids to migrate. Further west, fractures on trend with the clastic dike are filled with a graniodiorite dike. Burbank and Luedke (2008) note an important association of breccia dikes and hydrothermal activity in the area which focused ore in veins and "blanket" deposits. "Breccia or pebble dikes" associated with dioritic intrusive rocks and mineralized breccia pipes are also documented by Kelley and Silver (1946) in the Dunmore fissure system which is located ~8 kilometers south of Ouray.

Clastic dikes north of Ouray (Fig. 31) are exposed along strike for up to several kilometers. They are mostly vertical and trend ~90 E°, but the trends are quite variable in some outcrops. The dikes vary in thickness from several centimeters up to 3 meters; in some outcrops the breccia grades into bifurcating calcite-filled fractures. Outcrops range from matrix to clast supported with rounded to angular fragments ranging from less than 2 cm to 35 cm. The fragments are dominated by Proterozoic rock types: 1) phyllite and quartzite of the Uncompahgre Formation, 2) 1.7 to 1.4 Ga granites, and 3) minor felsic to mafic gneiss and schist that are similar to rocks in the 1800-1750 Ma Irving Formation and Twilight Gneiss (Gonzales and Van Schmus, 2007). Although the contacts with the country rock are generally sharp and well defined, angular fragments of adjacent country rocks are often incorporated into the clastic dikes. The abundance of Proterozoic fragments was also documented in the Bachelor breccia dike (summarized in Burbank and Luedke, 1981). The matrix of the clastic dikes consists of medium- to very coarse-grained sand and granules composed of quartz, biotite, and feldspar (Burbank and Luedke, 2008). The rocks also contain secondary calcite, chlorite and epidote which imparts a green tinge to most outcrops; in a few locations minor pyrite, chalcopyrite, and malachite were noted. Compared to the Placerville dikes, the matrix in the Ouray dikes is much finer grained.

West of Ouray, in the drainages of Canyon Creek and Angel Creek, 1-meter thick clastic dikes cuts the Pennsylvanian Hermosa Group; dikes at both sites trend about N60˚E. In Angel Creek, the clastic dike dips ~90˚ and contains numerous angular to subangular fragments of quartzite and phyllite that are up to 10 cm in maximum dimension (Figs. 31, 36), set in a fine-grained sandy matrix. Locally, the dike has entrained angular fragments of adjacent sandstone and limestone that are up to 50 cm in length. Numerous veinlets of calcite and quartz cut the dike.

At Stony Mountain, about 15 miles west of Ouray, a clastic dikes cuts ~27 Ma (Gonzales, 2015) gabbro of the Stony Mountain stock (Fig. 37). The dike trends ~350˚ and is about 1 meter thick, and is exposed in a vertical fracture that cuts the gabbro. Most of the fragments in the clastic dike are gabbro from the stock along with Proterozoic slate and quartzite. Igneous clasts are highly altered with sericite pseudomorphs after plagioclase and chlorite pseudomorphs after mafic minerals. The clasts are angular to subangular and up to 15 (?) cm in maximum dimension and set in a fine-grained matrix dominated by angular to subangular grains of quartz, sericite, chlorite, opaque minerals, and calcite cement. Angular to subangular fragments, up to 1 cm in maximum dimension are common and are dominated by quartzite, chert (?) or fine-grained quartzite, chlorite + sericite-rich phyllite, and fragments of chlorite. The dike is cut by numerous veinlets of quartz and calcite that in some zones define hydrothermal breccia. Fragments in the dike exhibit variable degrees of alteration to chlorite, and Fe-oxide stain from the alteration of pyrite is concentrated in the clastic dike.

Zircons extracted (n = 307) from the clastic dikes north of Ouray yield ages from 927 to 1998 Ma with dominant clusters from 1365 to 1607 Ma and 1679 to 1998 Ma defined by peaks at 1427 Ma and 1729 Ma, respectively (Fig. 38). There are also two zircons with ages ~2600 Ma, and ten zircons with ages between 927 and 1227 Ma. These ages do not correlate to any exposed rocks in the region, but all of the zircon ages from 1300 to 1800 Ma are from basement or reworked basement sources in the region. Another pronounced peak on the probability plot at 64 Ma indicates a high proportion (n ~ 80) of Laramide zircons from plutonic rocks in the area. These age data reveal that the clastic dike was emplaced after ~64 Ma. The clastic dikes in the Ouray area do not cut the volcanic rocks of the San Juan Formation that were deposited ~30 Ma.

The clastic dike sample collected at Stony Mountain contains zircons from 2542 to 25 Ma (Fig. 39). These zircons were derived from Proterozoic basement, Paleozoic to Mesozoic sedimentary, and late Mesozoic to Cenozoic igneous rocks. There are sixty four zircons from 1807 to 1000 Ma that indicate a basement source. The sample also contained seven zircons from 75 to 63 Ma that a consistent with Laramide intrusive rocks in the area. Zircon ages from 36 to 25 Ma were sourced from Oligocene intrusive and volcanic rocks including the Stony Mountain stock; 143 zircons range from 28 to 25 Ma. These zircons define a probability peak at 27.3 Ma which similar to the 27.5 ± 0.49 Ma age (Gonzales, 2015) for the stock. On the north flank of the Stony Mountain stock there is a small plutonic of quartz-porphyry granite (unit Trh) that is exposed. The granite is assigned an age of 12.1 ± 0.070 Ma. A dike of the granite cuts the Stony Mountain stock, but no fragments of it were found in the clastic dike which hints that the clastic dike was emplaced after ~27 Ma but prior to ~12 Ma.

Evidence gained in recent studies by Gonzales and Fort Lewis College geology students supports the previous interpretations (Burbank, 1930; Haff, 1944; Kelley and Silver, 1946; Bush et al., 1959; Bush et al., 1960; Burbank and Luedke, 2008) that clastic dikes exposed in the western San Juan Mountains formed by rapid subsurface release of gas which transported Proterozoic to Mesozoic sedimentary clasts to the point of deposition, as opposed to "sandstone" dikes formed by remobilization of sediment at a given stratigraphic position.

Field relations and zircon populations reveal that the clastic dikes in the Ouray area were not produced in a single event, but formed in several different generations. Those exposed north of Ouray contain ~65 Ma zircons from adjacent Laramide intrusive rocks, but do not cut the ~30 Ma San Juan Formation (Burbank and Luedke, 2008; Gonzales, 2015). At Stony Mountain, the clastic dike erupted into the ~27 Ma stock, but appears to be older than a ~12 Ma dike that intruded the stock. There are no age constraints on the "pebble" dike related to mineralized breccia pipes at Silver Gulch south of Ouray but these are likely Oligocene in age given that intrusive rocks related to breccia pipes at Red Mountain yield an age of 24.03 ± 0.24 Ma (Gonzales and Larsen, 2017).

The Cutler Formation in the Ouray area consists of arkosic conglomerates and sandstones and red siltstones and shales. Its thickness varies from about 2,150 ft north of Ouray to zero where it is truncated below a base-Triassic unconformity on the north side of the Ouray Amphitheater. This area was tectonically active during Permian time and a large paleo-drape on the west side of the valley is visible from Rotary Park (Fig. 34).

**Drive back to Ouray, take turn onto CR 361 just south of Ouray. Drive about 4 miles to start of hike to Angel Creek.**

At Angel Creek we will examine the clastic dike (Fig. 36) and altered porphyritic granodiorite in the Pennsylvanian Hermosa Group.

The Hermosa exposed in the Angel Creek streambed is in the uppermost part of the formation and consists of coarse arkosic sandstones and conglomerates, marine limestones, and shales. In the lower part of the exposure there is a possible small valley fill where a conglomerate cuts through a limestone bed and scours more than ten feet into an underlying sandstone bed.

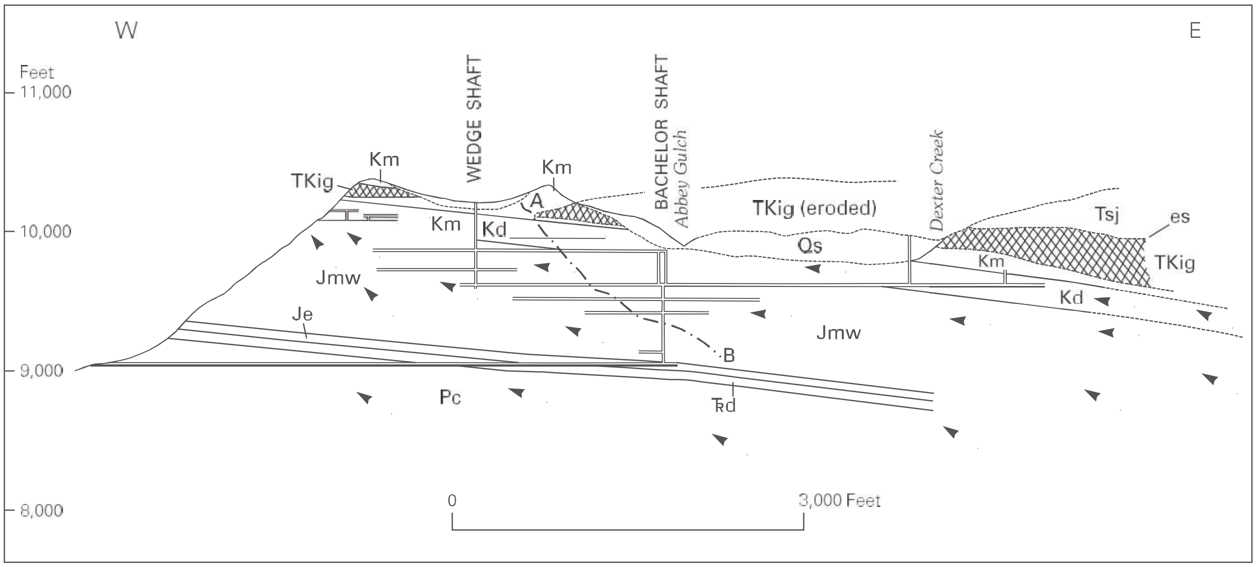



**Figure 35. This description was taken directly from Burbank and Luedke (2008).** Longitudinal section along the plane of the Bachelor mine workings, vein, and clastic dike indicating the probable course (arrows) of the clastic dike injection. Line A–B is the junction of the Bachelor fracture and the south split or Pony Express fracture. Pc, Cutler Formation; Ƭd, Dolores Formation; Je, Entrada Sandstone; Jmw, Wanakah and Morrison Formations, undifferentiated; Kd, Dakota Sandstone; Km, Mancos Shale; TKig, intrusive granodiorite; Tsj, San Juan Formation; Qs, landslide debris; es, early Tertiary erosion surface. Modified from Burbank (1930, p. 198).


**Figure 36.** (A) Photograph of ~1 m wide clastic dike that cuts the Pennsylvanian Hermosa Formation in Angel Creek. This dike contains a large angular block of sandstone from surrounding country rock that was entrained during emplacement of the dike. (B) Close up of outcrop showing subangular to subrounded pebbles and cobbles of Proterozoic Uncompahgre Formation and lower Paleozoic sedimentary rocks in a coarse sandy matrix. The dike varies from clast to matrix dominated.


**Figure 37.** General geology of the Stony Mountain stock which is cut by a clastic dike on the east side. Volcanic rocks ranging from 30 to 27 Ma are host to the plutonic rocks in this area. The Mt. Sneffels-Stony Mountain stock was emplaced at 27.5 ± 0.49 Ma age (Gonzales, 2015) and is cut by a quartz-phyric granite emplaced at 12.1 ± 0.070 Ma. The clastic dike is not cut by the granite, but there are no fragments of the granite in the clastic dike. The sample for U-Pb analyses was obtained from a steep chute on the east side of Stony Mountain at 37.98141N, 107.76585.

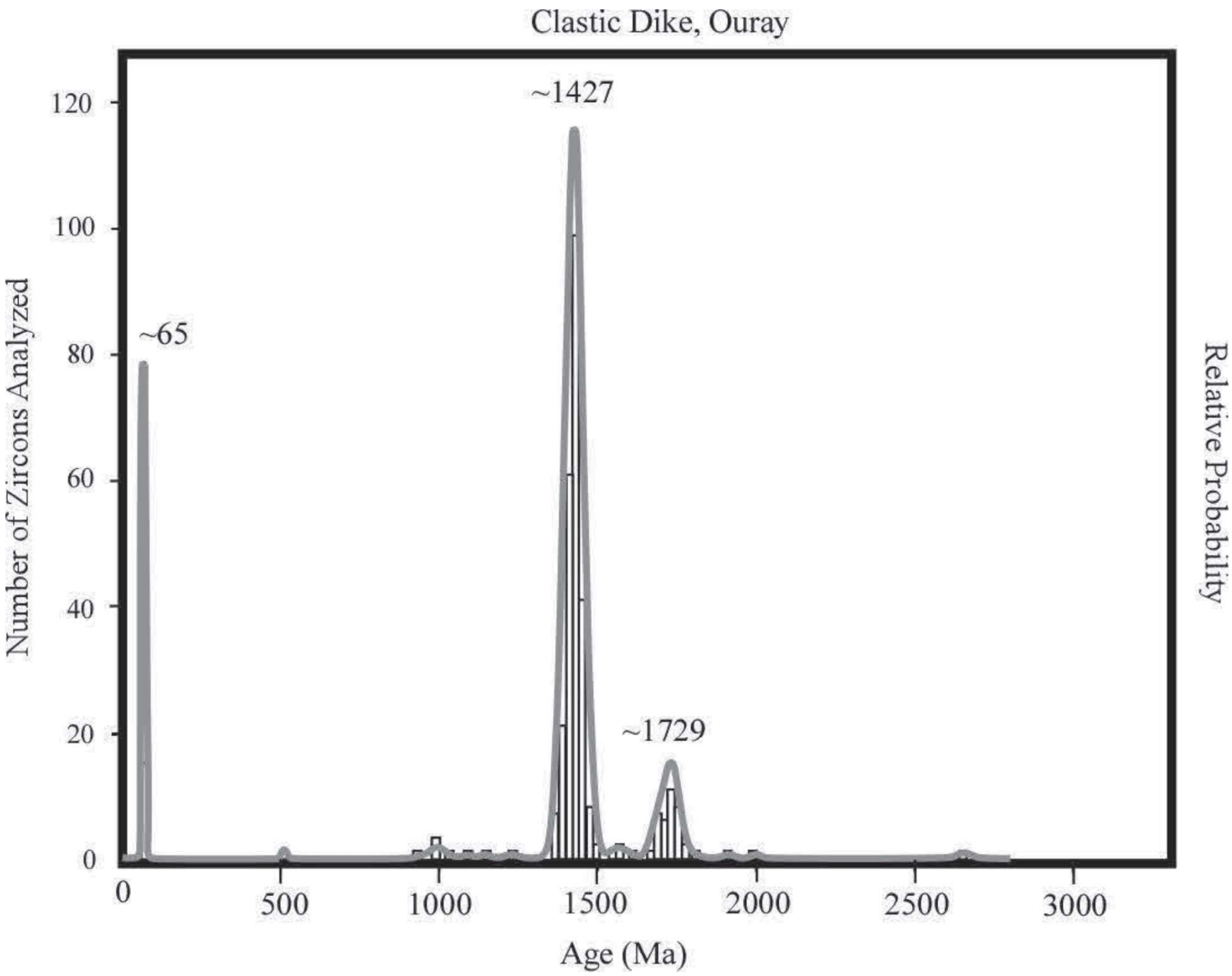



**Figure 38.** Probability plot for the detrital zircons from the clastic dike sampled near Ouray. These data are dominated by small populations of zircons from Proterozoic basement rocks to Paleozoic and Mesozoic sedimentary rocks. The dominant peak at ~65 Ma indicates that most of the zircons in the clastic dike were entrained from adjacent Laramide granodiorite plutons.

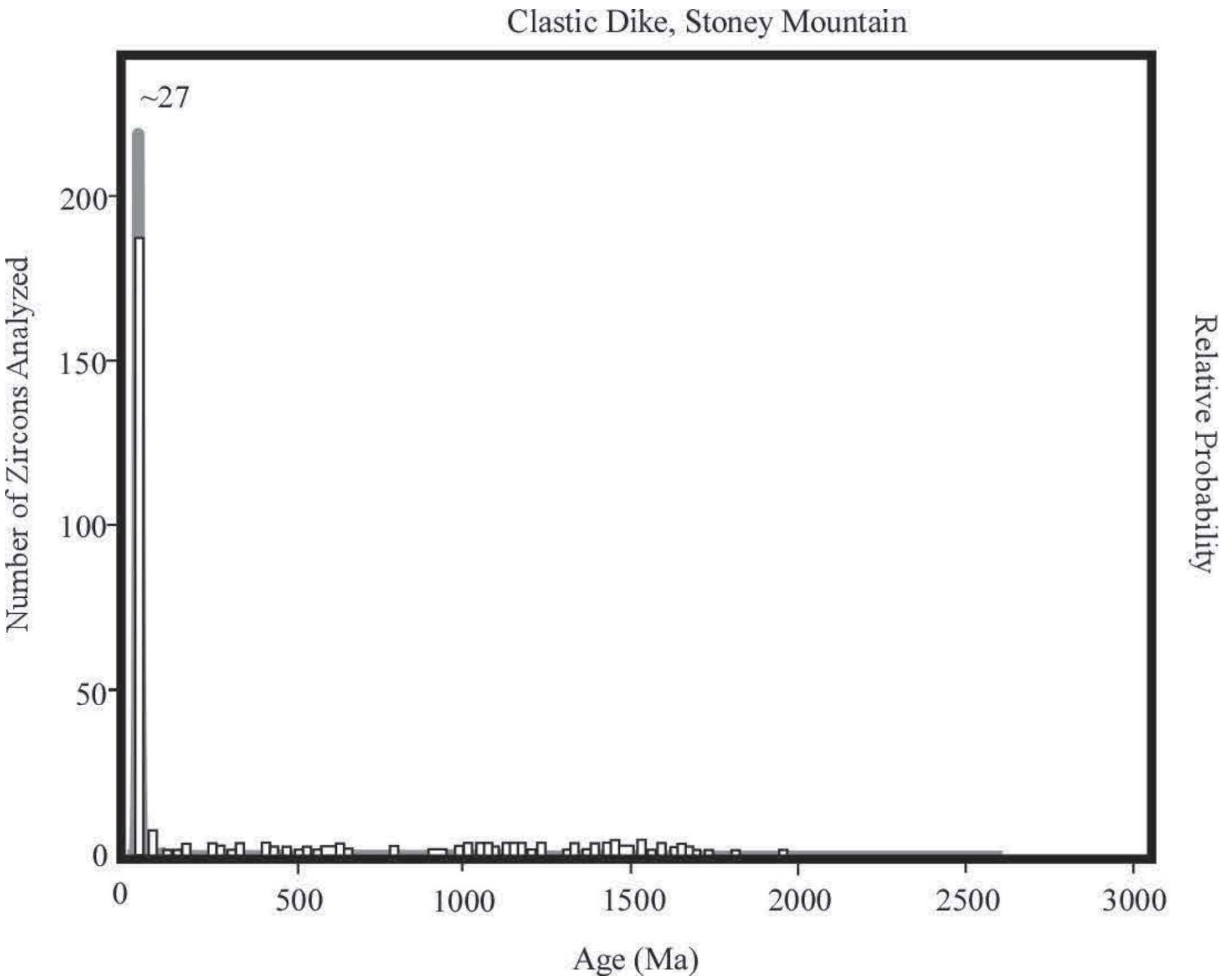



**Figure 39.** Probability plot for the detrital zircons from the clastic dike sampled at Stoney Mountain. The dominant peak at ~27 Ma indicates that most of the zircons in the clastic dike were entrained from the Stony Mountain stock with minor contributions from Proterozoic basement rocks to Paleozoic and Mesozoic sedimentary rocks.

**FCGS Ouray Field Trip 2019**
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