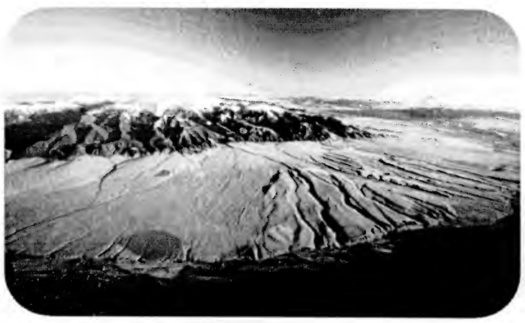
A STEREO PICTURE GUIDE TO SOME

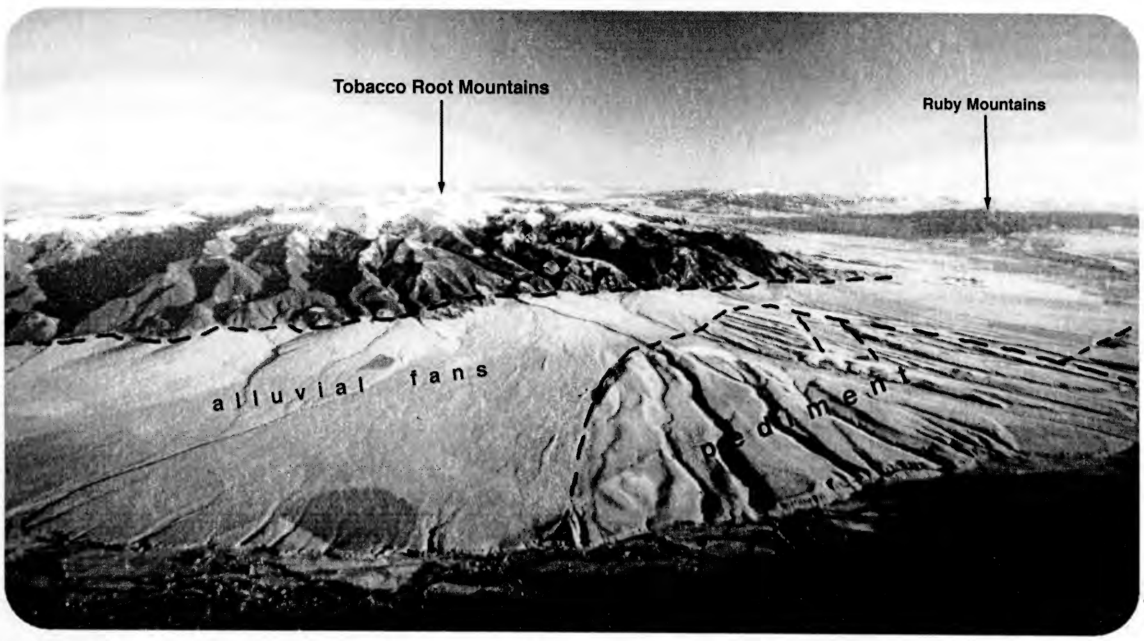
FAULTS, FANS, AND PEDIMENTS OF SOUTHWESTERN MONTANA

BY

HUGH DRESSER

1996





You are looking southeastward at a dissected pediment surface preserved in a horst in the Jefferson Valley. Alluvial fans bury the pediment along the mountain front. Dashed lines follow faults. Because the last episode of pediment formation took place during the arid climate between the Bull Lake and Pinedale glaciations, about 70,000 years ago, the last fault movements and the fans must postdate that episode.

INTRODUCTION

A sequence of stereo oblique aerial photos is used to acquaint you with some of the faults, alluvial fans and pediments of southwestern Montana. The tour starts on Dome Mountain in the Yellowstone Valley, then takes you to the Hebgen area, the Madison Valley, and thence to the Centennial Valley and the Tendoy Mountains. Next we look at a series of NW-striking, NE dipping Precambrian faults that have strongly affected subsequent structures. These flank the Blacktail Range, cut the Ruby Mountains, and extend up into the Melrose area. The aerial tour continues with a look at the pediments in the Divide area and then flies over to the Highland Mountains and the western side of the Jefferson Valley where glacial floods bracket the development of pediments and the faults that cut them. We look at the faults, alluvial fans, and pediments on the eastern side of the Jefferson Valley and around Bull Mountain. Our last flight takes us back down to the northern Ruby Mountains to look at evidence that suggests they may still be rising.

To see the stereo pairs in three dimensions at the top of each page you need to relax your eyes and stare straight ahead so that you see the right image with your right eye and the left image with your left eye. The images will float apart and merge in the center, giving you three images. At first this central image may be out of focus, but if you stare at it long enough, your mind will give up and focus even though your eyes are not converging on it. If all fails, you can use a pocket stereoscope to see the images in three dimensions. It simply forces you to look at the respective images with the proper eyes. The three dimensional models that you will see can only be seen with the aid of these pictures. Your eyes are about three inches apart, and you can see stereo for about 1000 feet. These pictures were taken from a moving plane with a picture base of anywhere from 100 to 300 feet. With this enhanced eye base you can see three dimensions for miles.

FAULTS

The faults we are going to see are mostly Tertiary normal faults that result from extension of the earth's crust. Southwestern Montana is at the northeastern corner of the Basin and Range Province of western North America. Across Nevada and Utah the extension may exceed 100 percent. Here in southwestern Montana, it is much less. As the area stretched west-east, Precambrian faults that trended NW and NE became normal faults. These faults had acted as reverse faults during the Laramide compression. Some of the north-trending thrust faults squeezed during the orogeny also became normal faults, the Tertiary beds rotating as they slid down their concave surfaces.

ALLUVIAL FANS

Alluvial fans are cone-shaped deposits of sediment that accumulate where the stream has insufficient gradient to transport its load. The stream deposits its sediment until a gradient is produced that allows it to transport its load. Its surface is a slope of transportation. In Montana, most of the alluvial fans develop when range front faults drop the valley and reduce the gradient of the streams flowing out of the mountains to the master drainage in the valley. As the master drainage continues to degrade, the streams will incise into their alluvial fans. Thus, the degree to which the streams are incised into their alluvial fans is a rough measure of the age of the fans and the faulting.

PEDIMENTS

This is my biased view of pediments. Pediments are erosional arid landforms. They form on the surfaces between streams. They are largely produced by rillwash and sheetwash floods where there is little vegetation to hold the soil. Sporadic and random thunderstorms, perhaps monsoonal, pelt the surface with torrential rain that runs down the slope as rills and sheets until it sinks into the parched surface, leaving a veneer of transported sediment on the eroded surface. Repetition of the process erodes the knobs and deposits in the hollows until a smooth surface of sheetwash and rillwash transportation is produced. The pediment is not graded to the streams because the runoff seldom reaches them. When it does reach the gullies, it erodes the steep gully walls even faster than it does the gentler pediment surface. Streams are usually incised below the surface of the pediment, for their drainage basins collect and concentrate the flow from the thunderstorms, enhancing their erosional prowess. Overland flow by sheetwash and rillwash is a weaker erosional process.

Pediments form best and most rapidly on rocks that break down into sand, for sand is the most easily eroded sediment size. In southwestern Montana the pediments are best developed on granitic rocks and Tertiary sediments. Some are also developed across limestones.

Changes in climate from humid to arid enhance the development of pediments. Deep weathering in a humid climate disintegrates the rock. When the climate turns arid, the vegetation dies and burns off in wildfires, leaving the deeply weathered regolith exposed to erosion. An episode of pedimentation follows. When the climate turns back to semiarid or humid, vegetation anchors the soil on the pediment, and the surface ceases to degrade. At this time the pediment is attacked from the sides by headward erosion of the incised gullies. Such changes in climate have occurred as the glaciers have waxed and waned in Montana. The last episode of pediment formation took place in Montana between the Pinedale and Bull Lake glaciations, about 70,000 years ago.

Pediments formed along all the stable mountain fronts at that time. The overland erosive processes that formed pediments even operated on mountain fronts bordered by alluvial fans, forming pediment surfaces across the alluvial fans. Because they form only in arid climates, all the pediments in southwestern Montana, whatever their elevations, were formed during this arid interglacial interval.

Where mountain fronts are now bordered by alluvial fans, the pediments have been dropped and buried by the fans within the last 70,000 years.

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O'Neill, J.M., Leroy, T.H., Stickney M.C., and Carrara, P.E., 1995, "Neotectonic Evolution and Historical Seismicity of the Upper Madison Valley and adjacent Madison and Gravelly Ranges in the Cliff Lake 15' Quadrangle, Southwest Montana": GSA Abstracts with Programs, Rocky Mountain Section.

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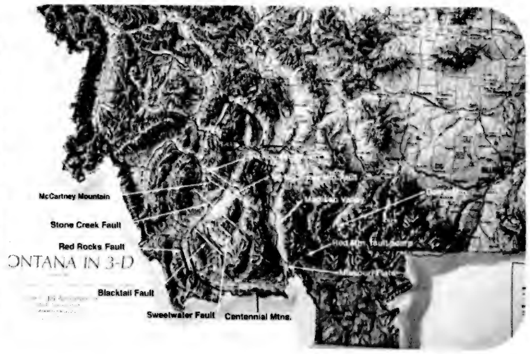
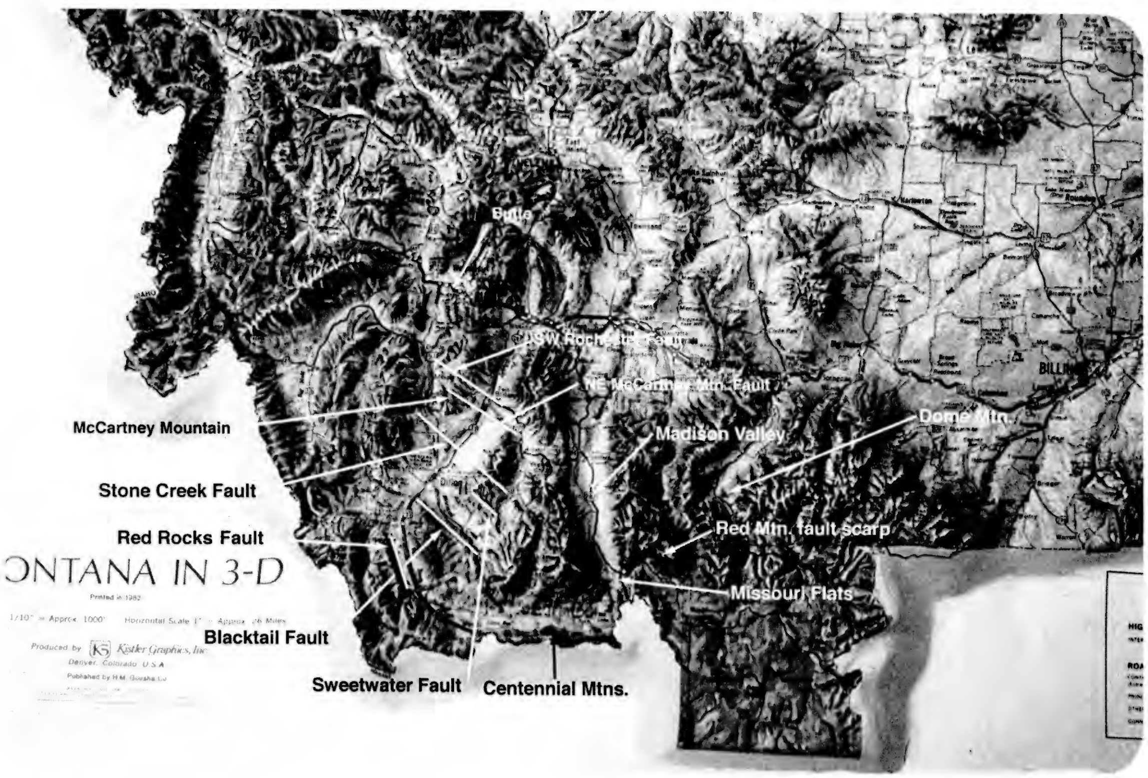
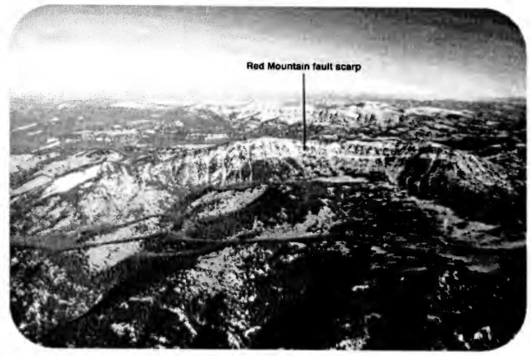
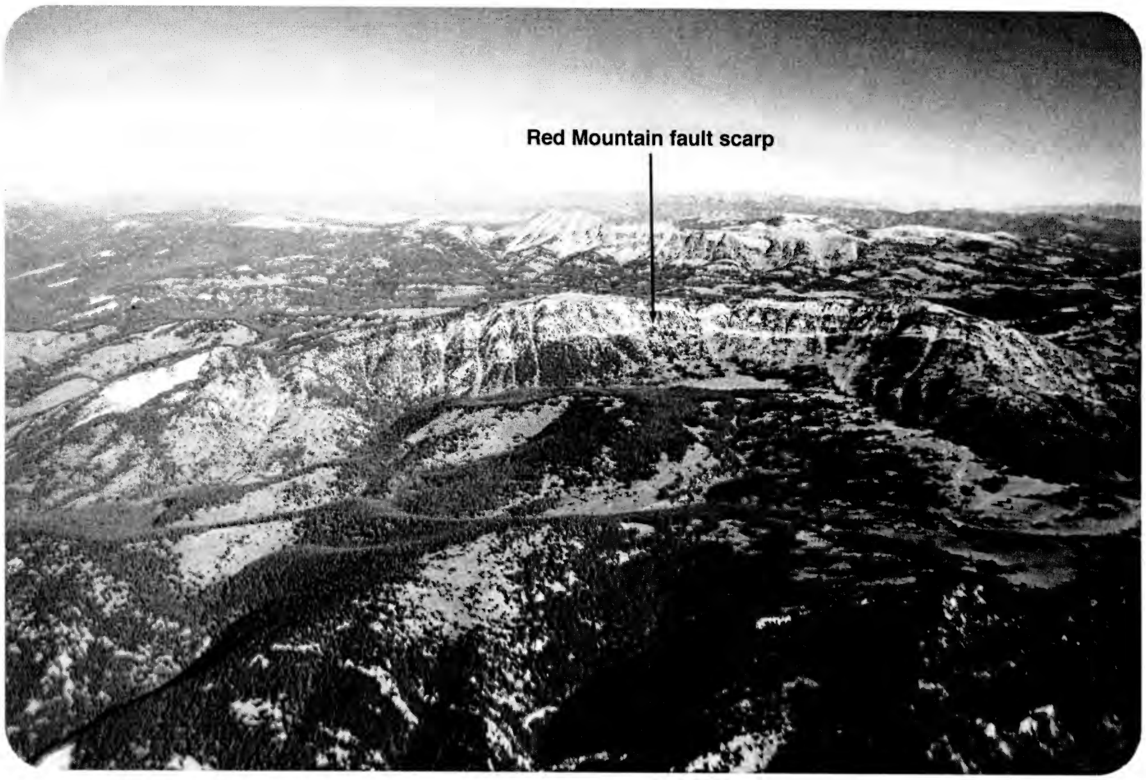




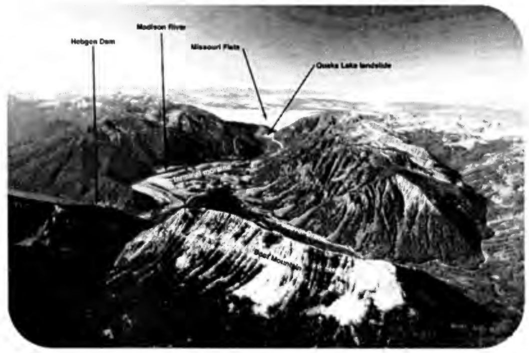
Index map showing the locations of the features shown on the next 25 pages.

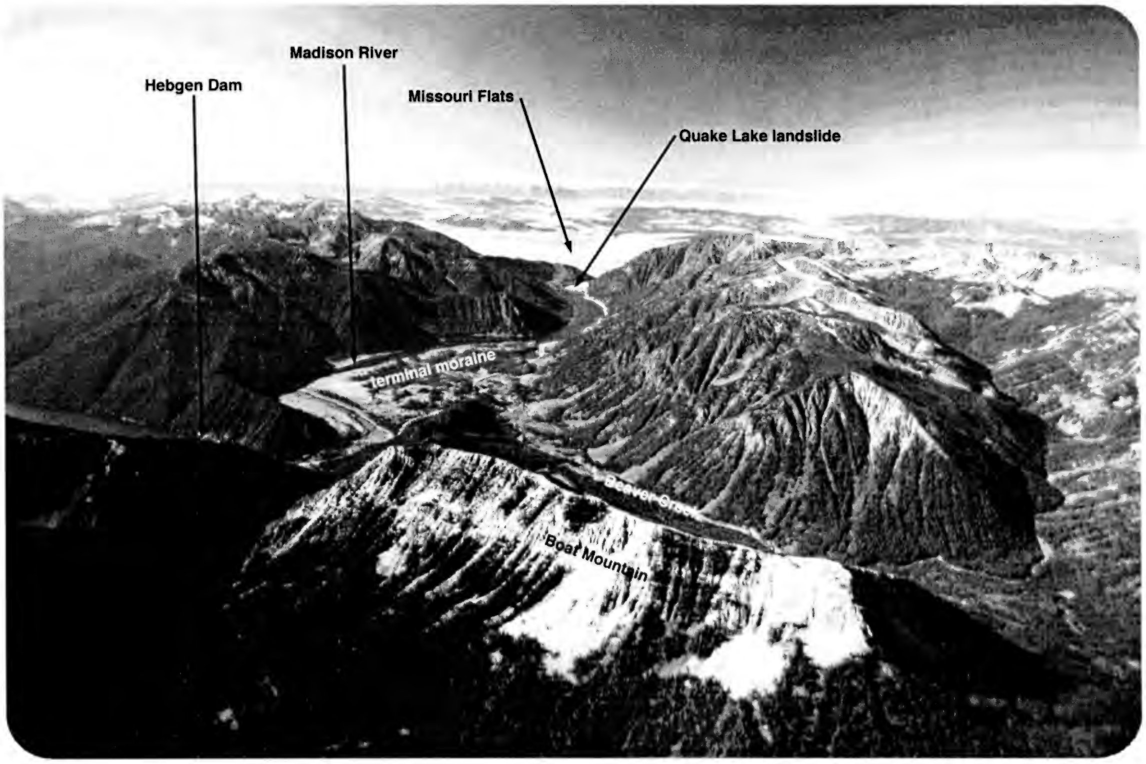
You are looking toward the southeast up the Yellowstone River at a fault scarp that offsets an alluvial fan at the base of Dome Mountain. The alluvial fan accumulated on the floor of the valley after the Yellowstone glacier, an outlet glacier from the Yellowstone Ice Cap, retreated up the Yellowstone Valley, perhaps 15,000 years ago.



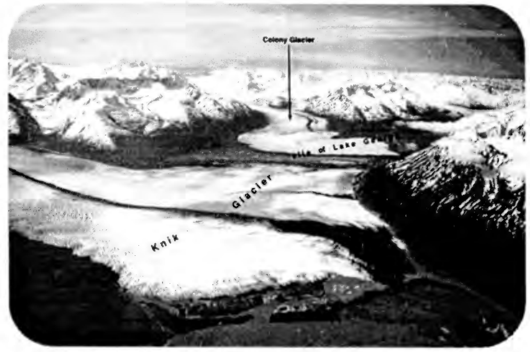


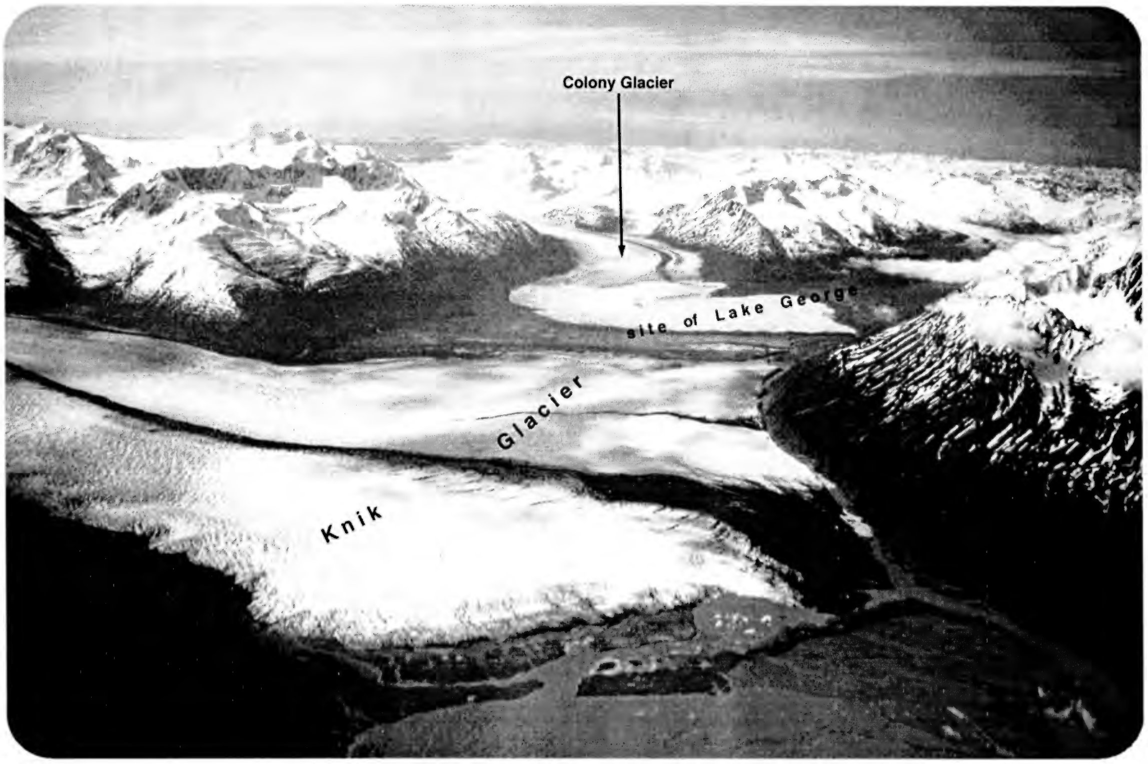
You are looking northward at the fault scarp on Red Mountain north of Hebgen Reservoir. The fault scarp is one of several produced during the 1959 Hebgen earthquake.



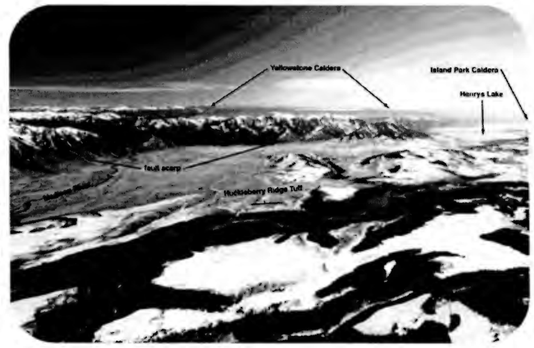


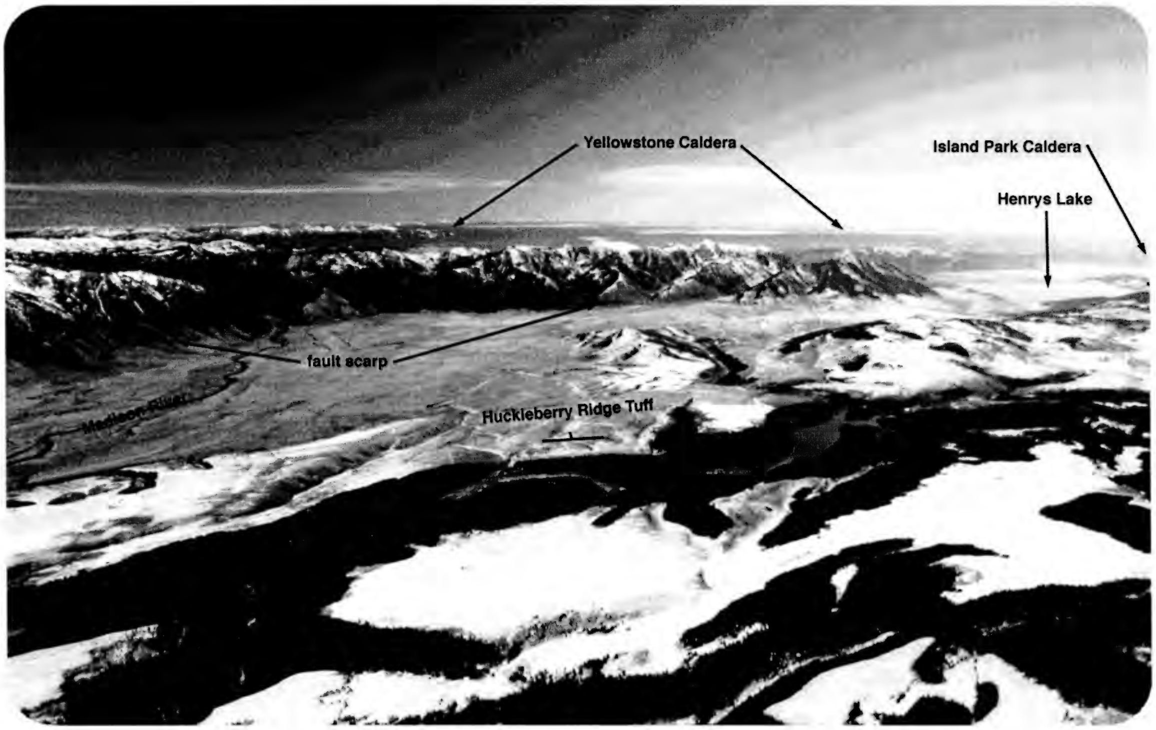
You are looking southwest at the landslide that created Quake Lake when it blocked the exit to the Madison River Canyon during the Hebgen Quake in 1957. The U.S. Corps of Engineers cut a spillway through the landslide to prevent an outburst flood if the landslide dam were to fail catastrophically. Ancient outburst floods from an ancestral Hebgen Lake may have occurred if the Beaver Creek Glacier blocked the Madison River. The glacier covered the rounded spur of Boat Mountain that points toward Quake Lake, and its terminal moraine fills Madison Canyon behind Quake Lake. The glacier ice appears to have been thick enough to block the Madison River by advancing against the far wall of the canyon, but there is no way to be certain of this. Some of the large boulders on the lower terraces of Missouri Flats could have been transported by outburst floods. A modern analog of this situation is Alaska's Knik Glacier shown on the next page.





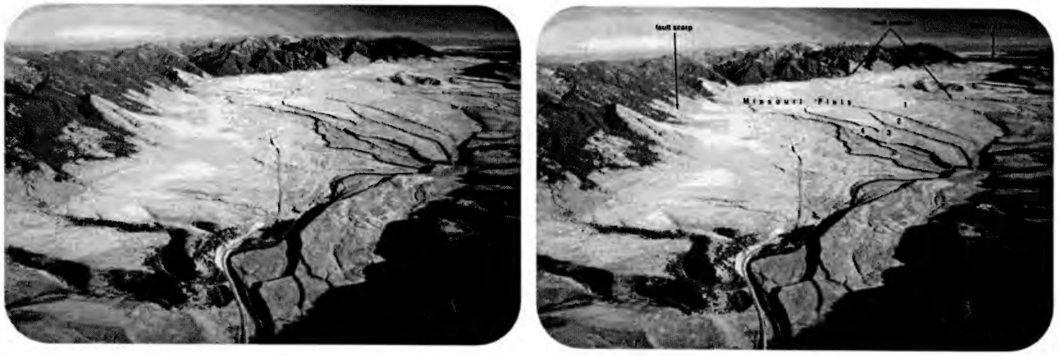
You are looking southeast at the Knik and Colony Glaciers in the Chugach Mountains of Alaska. Prior to 1968, the Knik Glacier would advance against the mountain on the right nearly every winter to block the valley and form glacial Lake George. Lake George would overflow the toe of the glacier in the spring, rapidly cut a channel through the ice, and discharge as a huge outburst flood down the Knick Valley into Cook Inlet. The Knik Glacier has retreated enough since 1968 that it no longer blocks the valley to form Lake George. A small undrained remnant of Lake George occupies a depression in front of the Colony Glacier.

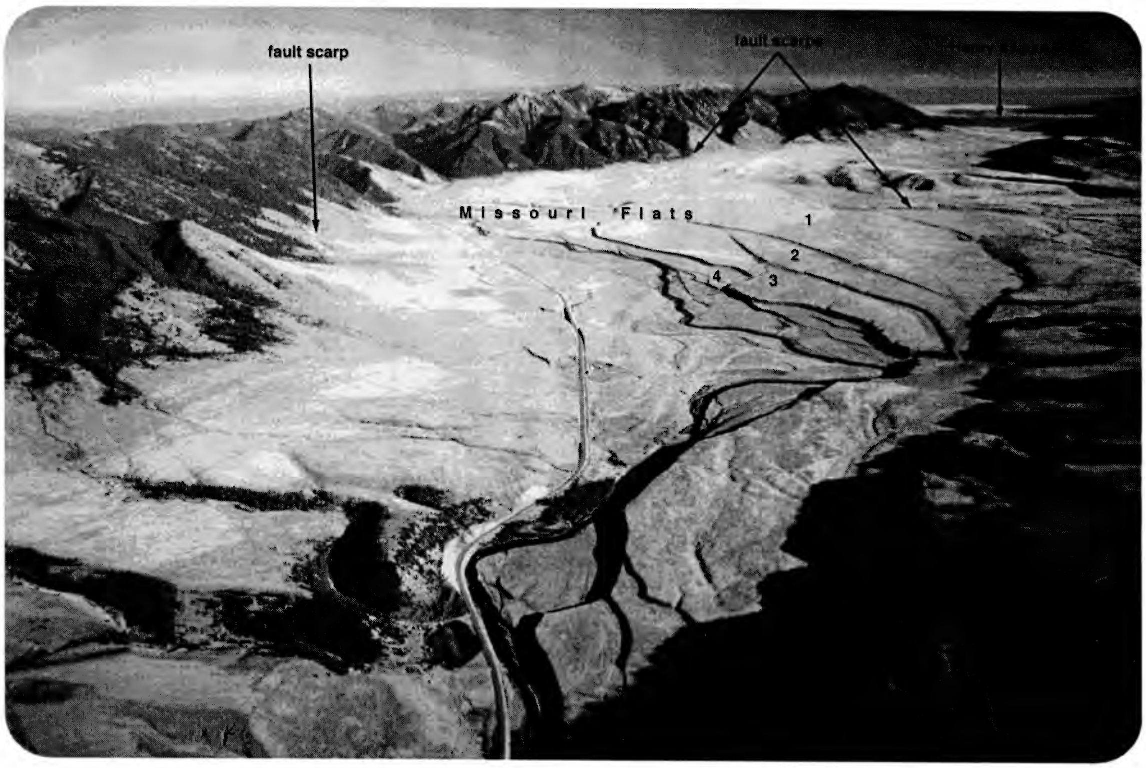




You are looking toward the southeast at Missouri Flats where the Madison River exits the Madison Range in SW Montana. Two million years ago the Huckleberry Ridge Tuff accumulated across Missouri Flats as a flat-lying tuff dropped by a series of immense ash flows issued from the site of the Island Park Caldera. Since then, movement along the fault in front of the Madison Range has dropped the Huckleberry Ridge Tuff about 1000 meters at the mountain front*, causing the tuff to tilt toward the mountains. If the fault dropped about two meters at a time, then the recurrence interval for the faulting would be about 4 thousand years. The Yellowstone Caldera is the site of the eruptions of the Mesa Falls and Lava Creek Tuffs, 1.2 million and 0.6 million years ago. The Island Park and Yellowstone calderas formed when the overlying terrain collapsed into magma chambers partially emptied by the expulsion of voluminous ash flows. An ash flow is a dense surge of highly gas-charged lava that explodes as it travels across the ground at speeds often exceeding 100 miles per hour (160 km/hr).

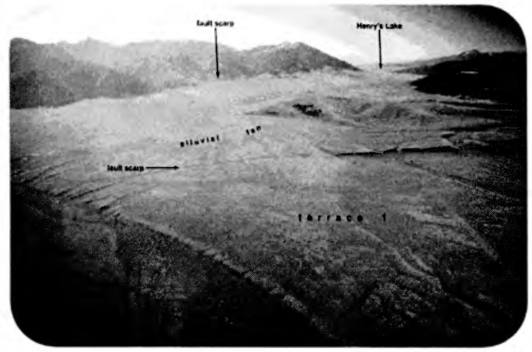
*Weinheimer, C.J., 1979, “The Geology and Geothermal Potential of the Upper Madison Valley between Wolf Creek and the Missouri Flats, Madison County, Montana” M.S. Thesis, Montana State University

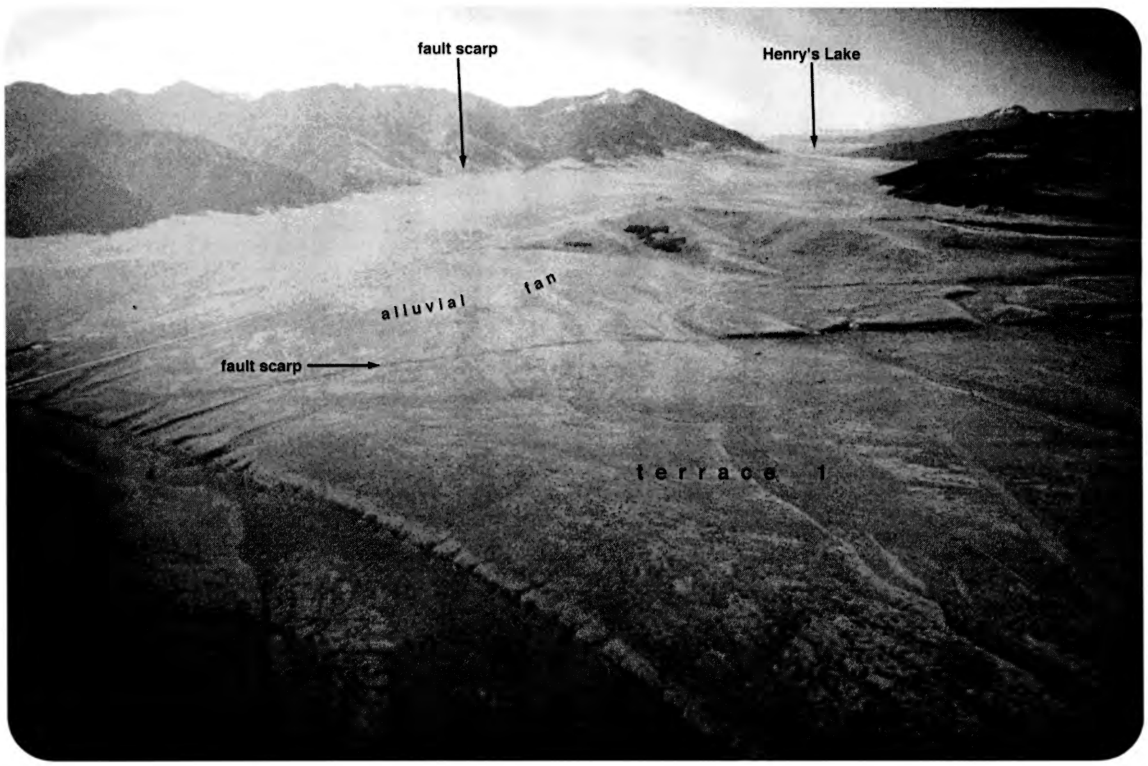




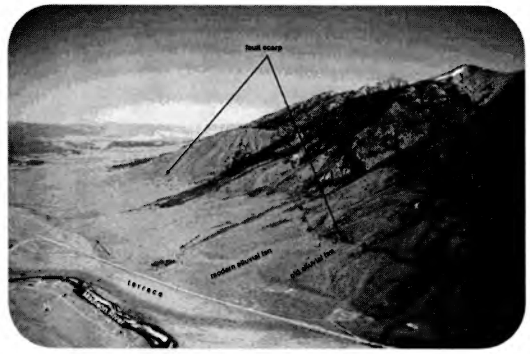
You are looking southeastward at terraces of the Madison River developed on Missouri Flats. The four major terraces are numbered from (1), the oldest, to (4), the youngest. The terraces are remnants of successive levels of the floodplains of the Madison River. Why are they developed here? Changes in discharge of the Madison River with alternate growth and rapid melting of the Yellowstone ice cap could produce first deposition, then erosion, as this sediment-filled basin subsided along the fault scarp that borders the mountain front. The Huckleberry Ridge Tuff, two million years old, has been tilted eastward as the Gravelly Mountains, behind you as you view this picture, arched upward. The resulting depression along the mountain front has been filled by alluvial fans from the Madison River and the smaller mountain streams. The terraces could be features carved on these fans by pulses of rapid downward erosion as the Madison River increased in discharge during phases of rapid melting of the Yellowstone ice cap. The oldest terrace, (#1), is partially covered by an alluvial fan that is cut by a fault scarp, shown in closer view on the next page.

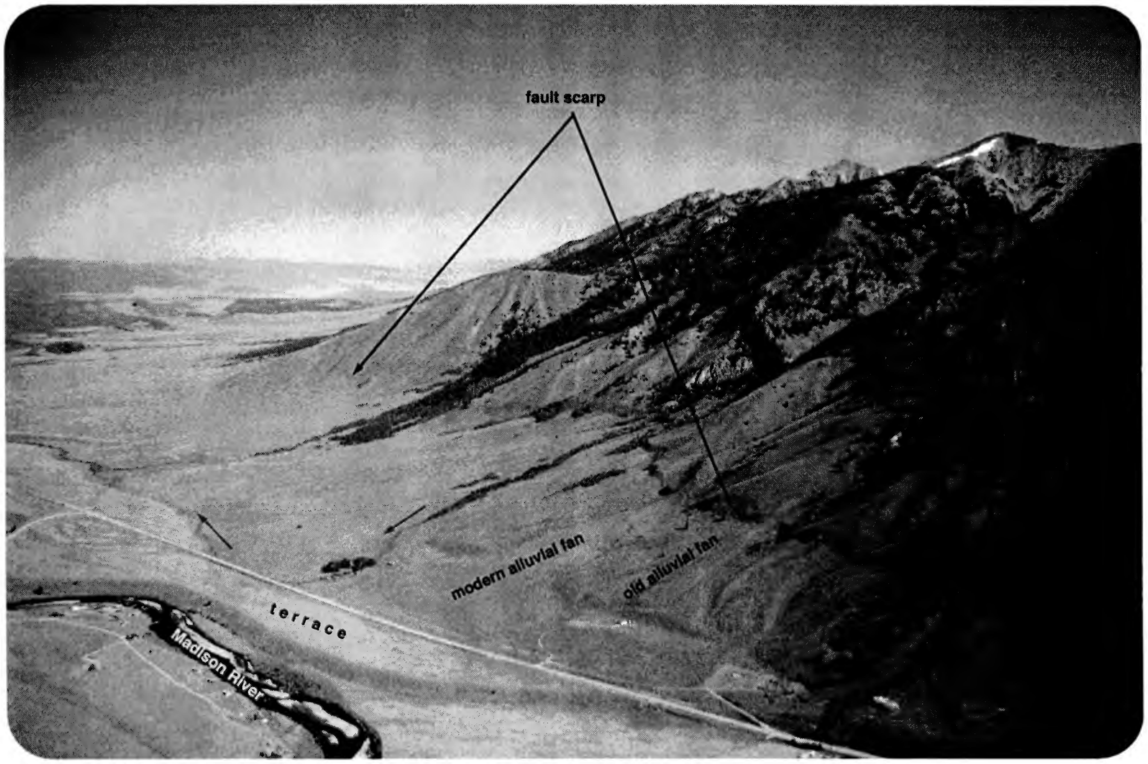
Another explanation for these terraces is that this whole area, mountains and flats, could be rising even as the flat subsides relative to the mountains. The increased elevation could cause the Madison River to incise, leaving behind remnants of its old higher floodplains.



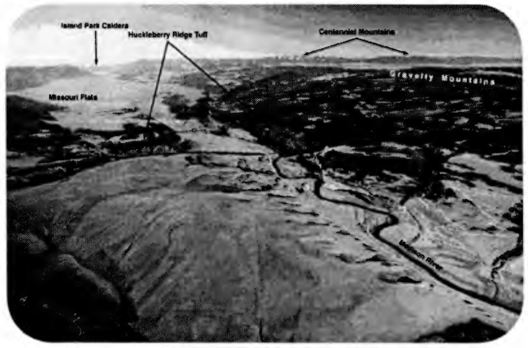


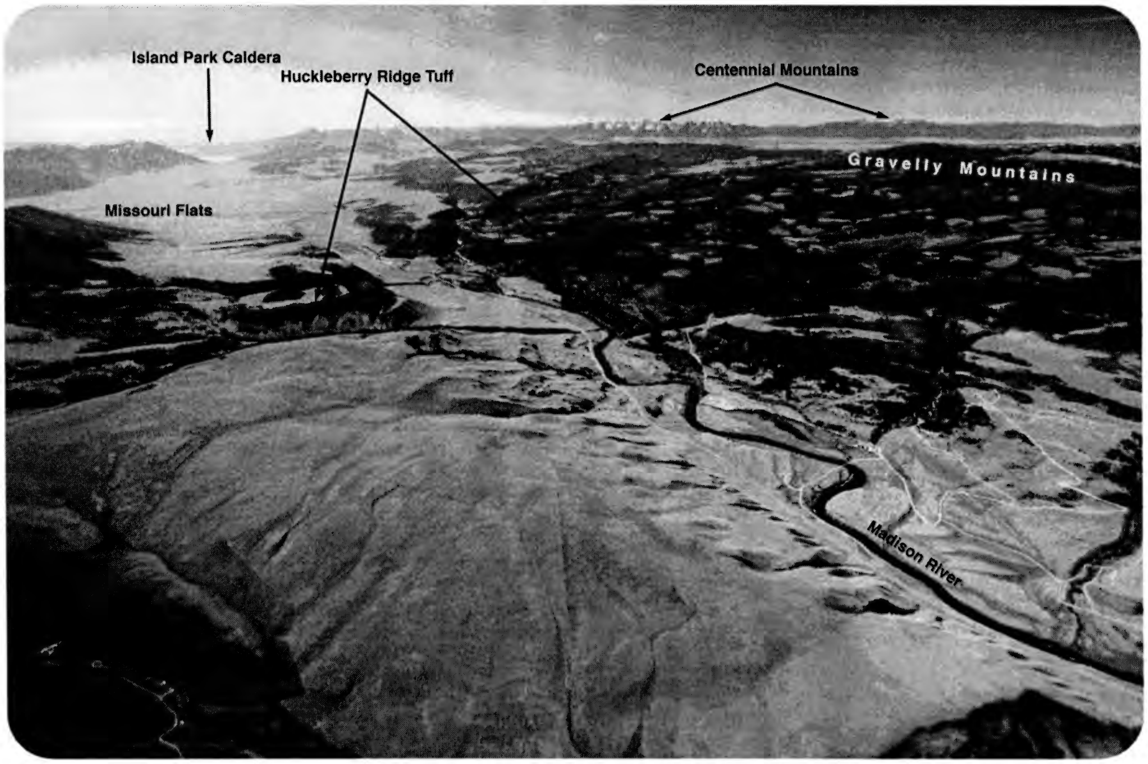
You are looking southeastward at the southern part of Missouri Flats. An alluvial fan partially covers the highest Madison River terrace (terrace 1), and a fault scarp cuts the end of the fan.





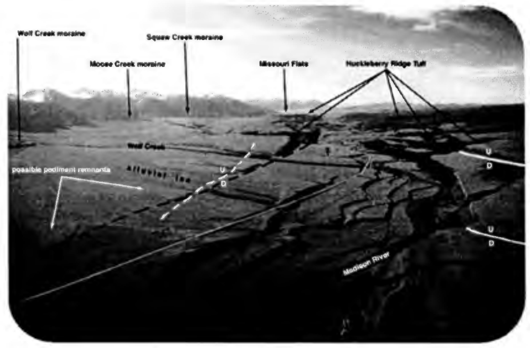
You are looking toward the northwest along the northeastern edge of Missouri Flats in southwestern Montana. The labelled terrace may correlate with terrace 2 on the other side of the Madison River. Modern alluvial fans partly cover the terrace. Old alluvial fans have been truncated either by a terrace or by a fault. The two gray arrows along the creek show its odd right-angle turn. Why didn't it continue straight ahead, cutting through the easily eroded terrace gravels to join the Madison River? Perhaps the terrace was tilted toward the mountain by the movement along the fault scarp.

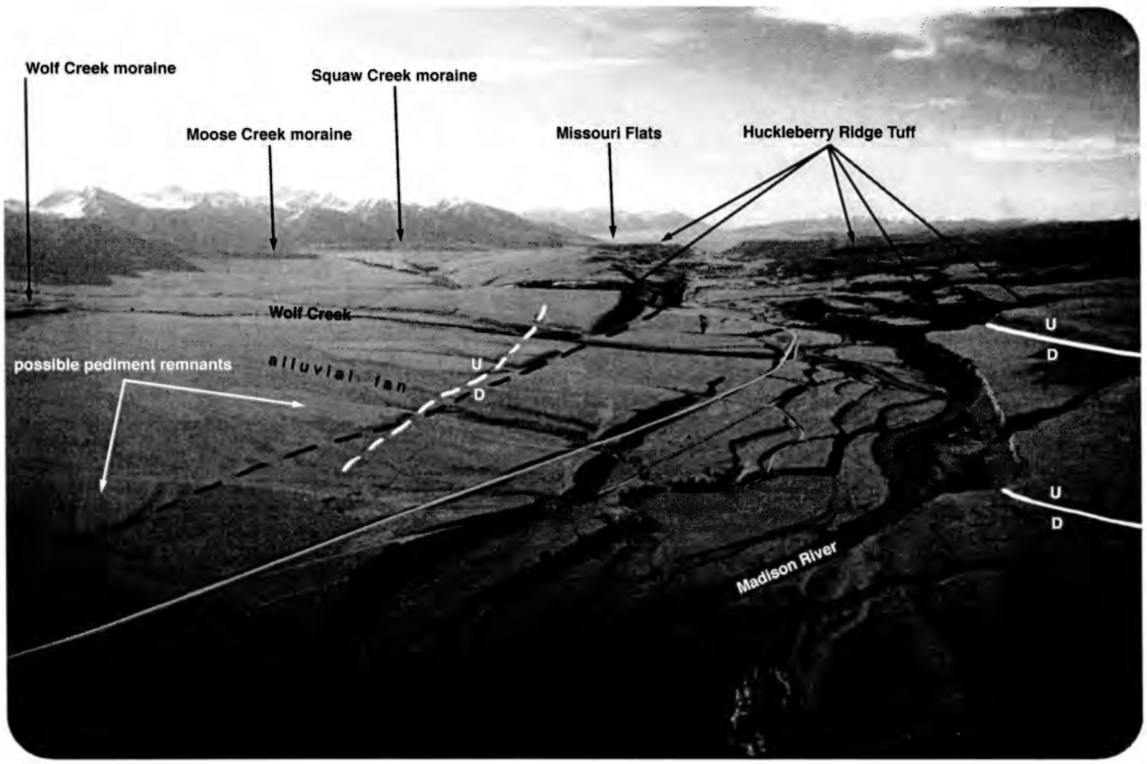




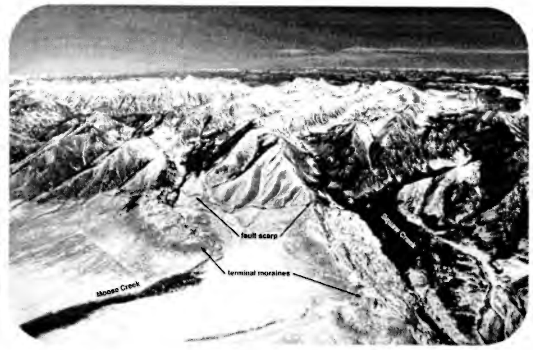
You are looking southward up the Madison River at the Gravelly Mountain arch. Two million years ago the Huckleberry Ridge Tuff surged from Island Park as a series of monstrous ash flows whose glass shards welded together to form a hard rock, an ignimbrite, that was nearly horizontal at the time it was deposited. It now dips eastward toward the range-bounding fault bordering the Madison Range to the east, and rises toward the west to 9,600 feet on the Gravelly Mountain arch. The Gravelly Mountains are rising and tilting the Huckleberry Ridge tuff on their east flank*. Paleozoic and Mesozoic strata on the top and west side of the Gravelly Mountains dip westward at about 25 degrees.

*O'Neill, J.M., Leroy, T.H., Stickney, M.C., and Carrara, P.E., 1995, "Neotectonic Evolution and Historical Seismicity of the Upper Madison Valley and adjacent Madison and Gravelly Ranges in the Cliff Lake 15' Quadrangle, Southwest Montana": GSA Abstracts with Programs, Rocky Mountain Section.

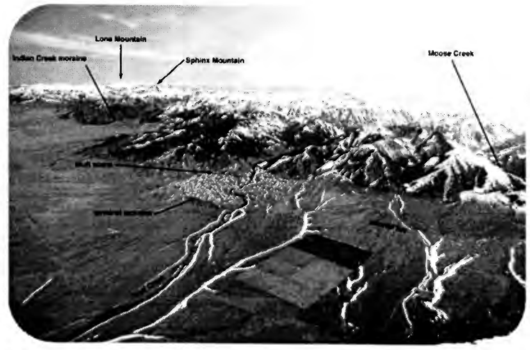


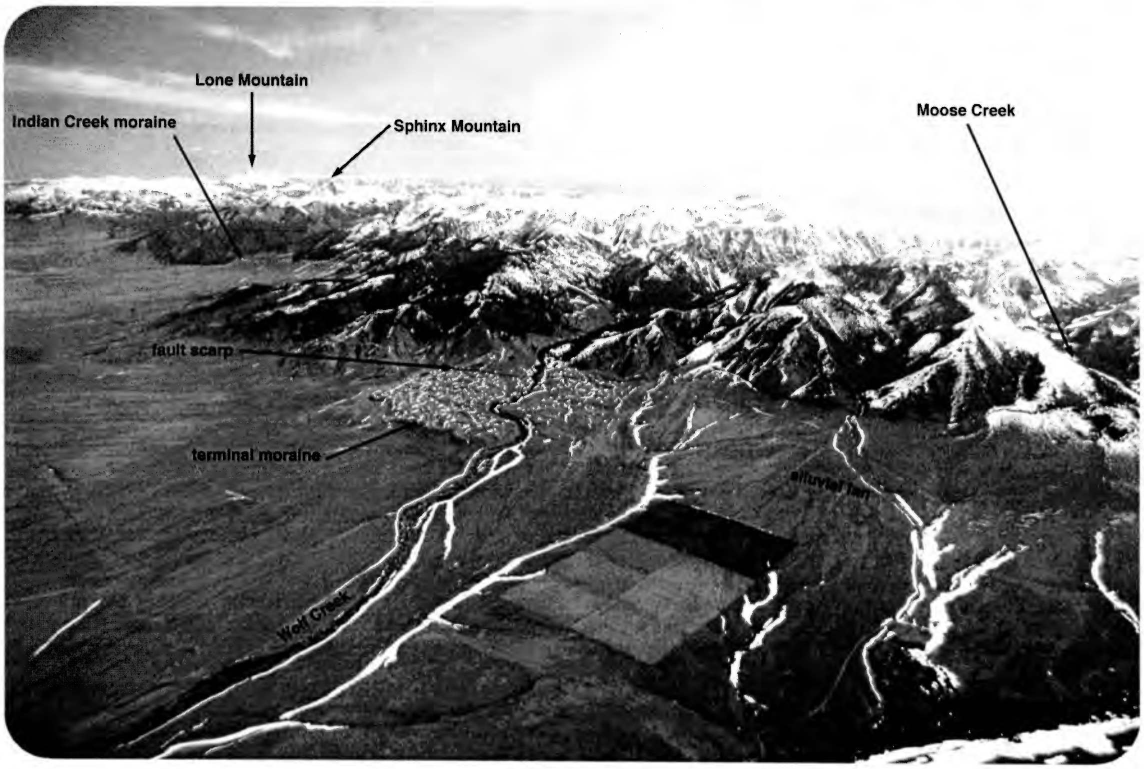


You are looking south up the Madison Valley. In Missouri Flats and north of Wolf Creek the river has well developed terraces carved on the Cenozoic basin fill. Between Missouri Flats and Wolf Creek the terraces are narrower and fewer beacuse the river has cut its valley through Huckleberry Ridge Tuff onto Cretaceous bedrock. The Wolf Creek alluvial fan partially buries an older surface that may be a pediment or an older fan. The dashed white line follows a low fault scarp that cuts the Wolf Creek alluvial fan and the Huckleberry Ridge Tuff. The solid white lines follow faults that offset the Huckleberry Ridge Tuff. The dashed black line could be a fault or an old edge of the Madison River valley cut laterally into the possible pediment. An east-west, cross-valley fault system probably separates the Cenozoic alluvium-filled basin in the foreground from the Cretaceous bedrock between Wolf Creek and Missouri Flats. The terraces you see here merge downstream with the floodplain of the Madison River until north of Ennis only one remains. Uplift of the southern Madison Valley area could be the cause. Picture taken June 23, 1983.

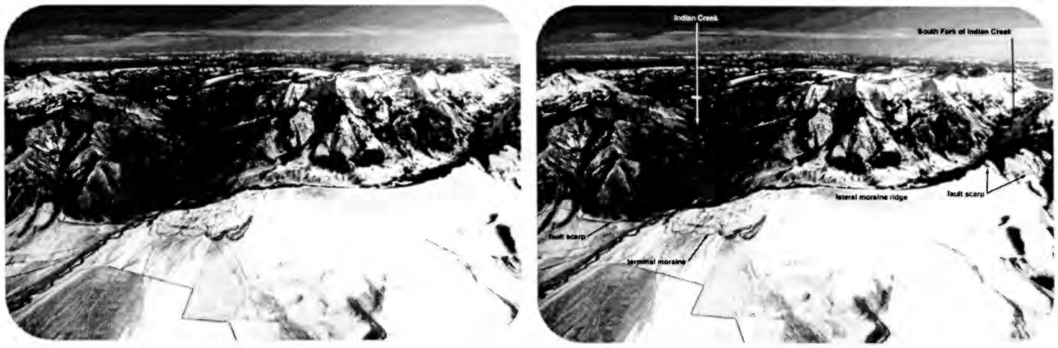


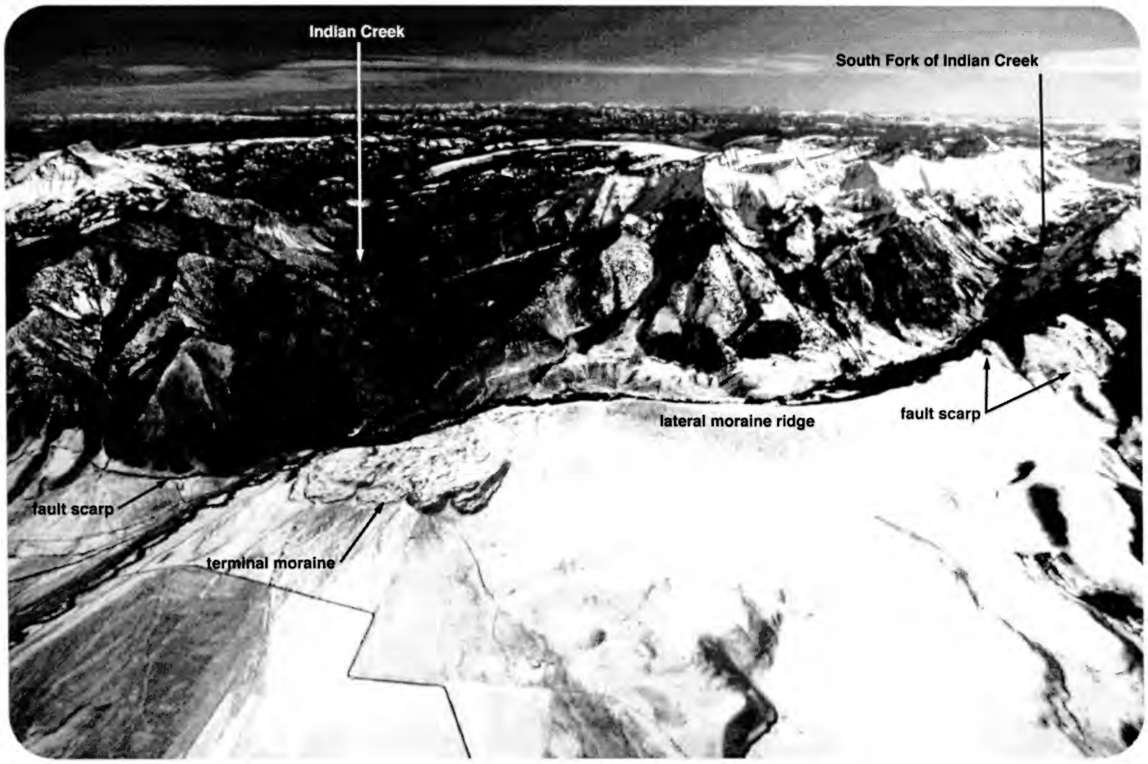
You are looking toward the east at a fault scarp that cuts the Moose Creek and Squaw Creek terminal moraines on the west side of the Madison Range in SW Montana. The moraines are mounds of unsorted dirt and rocks dropped and shoved by the ice when the glaciers were at their maximum extent about 18,000 years ago.



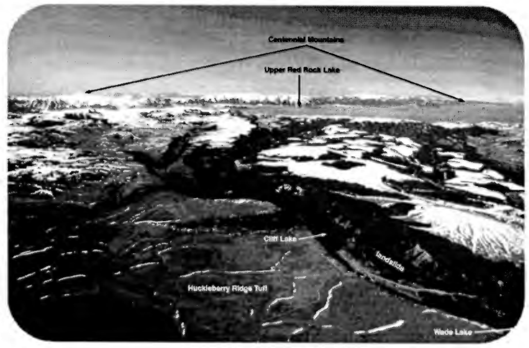


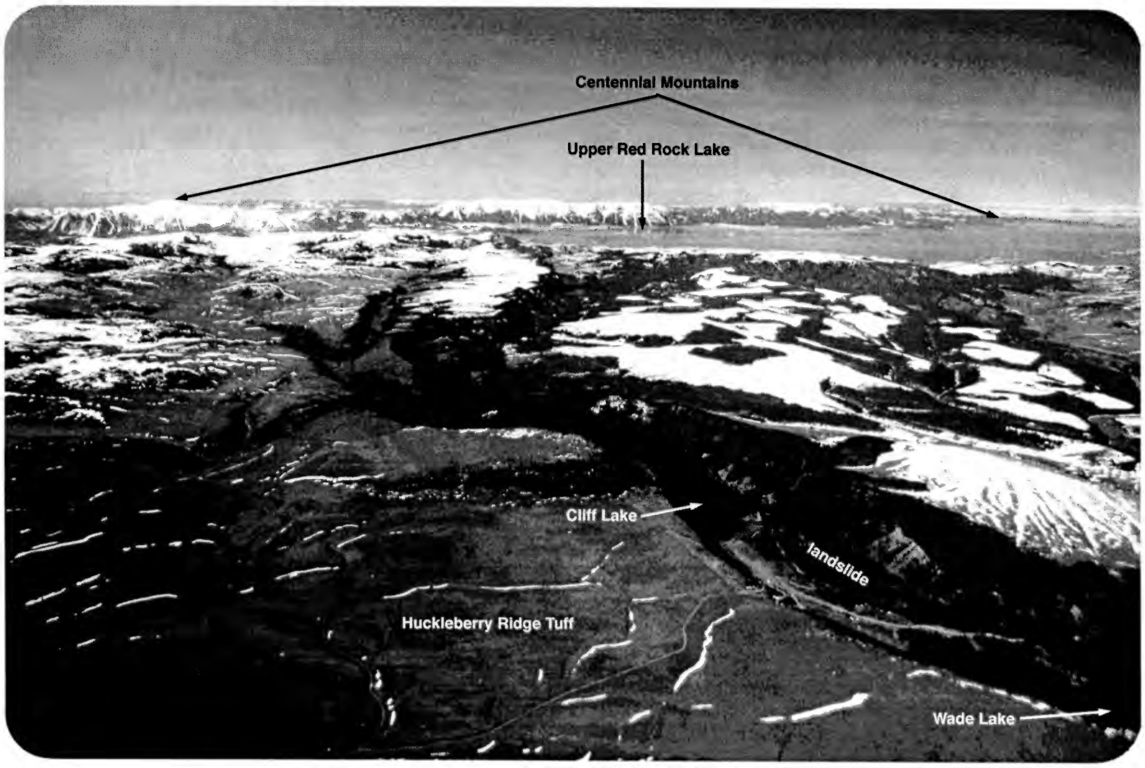
You are looking northeast at alluvial fans bordering the Madison Range in southwestern Montana. The terminal moraine at the mouth of Wolf Creek covers the Wolf Creek alluvial fan and is cut by the fault scarp, which becomes less prominent from Moose Creek northward. The Bad Luck Creek alluvial fan is the one that is labelled. The fault scarp appears to die out north of Wolf Creek, but another one develops to cut the Indian Creek moraine, as shown on the next page. Picture taken 4-30-83.



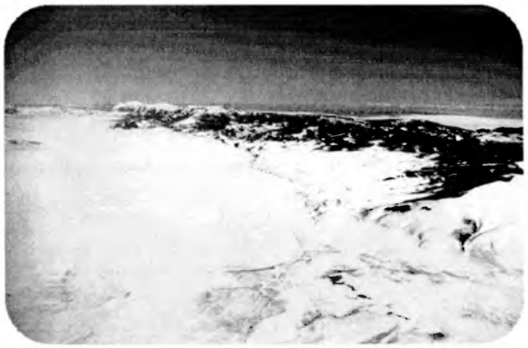


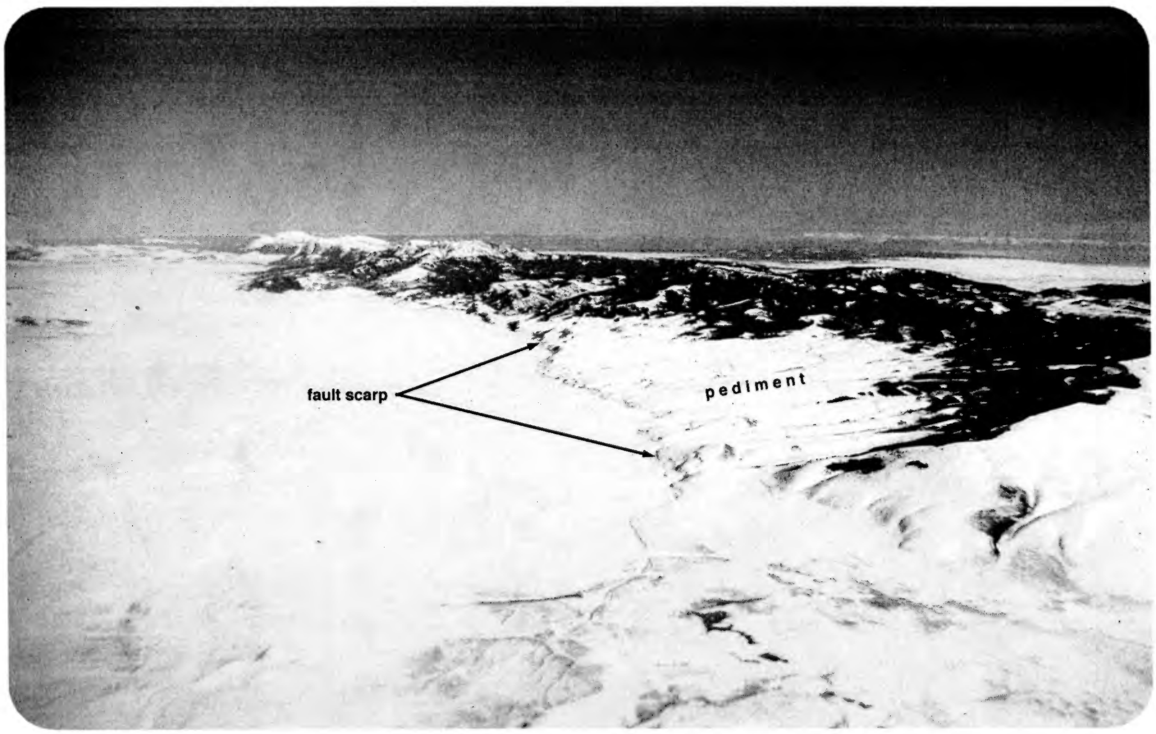
You are looking east at a fault scarp bordering the west flank of the Madison Range in south-west Montana. The fault cuts the lateral moraine on the right and presumably continues under the South Fork of Indian Creek, behind the lateral moraine, to join the fault scarp on the left. Picture taken 11-1-81.



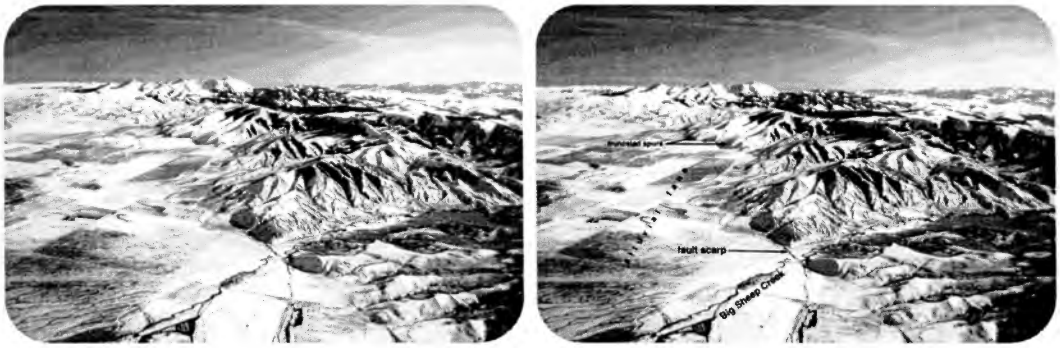


You are looking southwest toward the Centennial Valley bordered by the Centennial Mountains in the distance. The Centennial Valley has been dropped along faults and filled with Cenozoic sediments. A fault scarp occurs along the north side of the Centennial Mountains at the western end. In the foreground the Huckleberry Ridge tuff covers Cenozoic sediments to form benches on either side of Cliff and Wade Lakes, both dammed by landslides. The tuff is prone to landslides because it is a dense welded tuff resting on soft and slippery Cenozoic sediments. Picture taken 6-23-83.



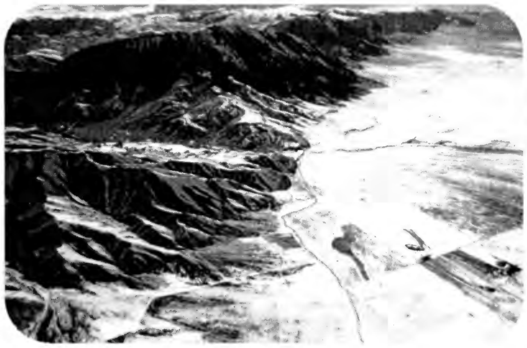


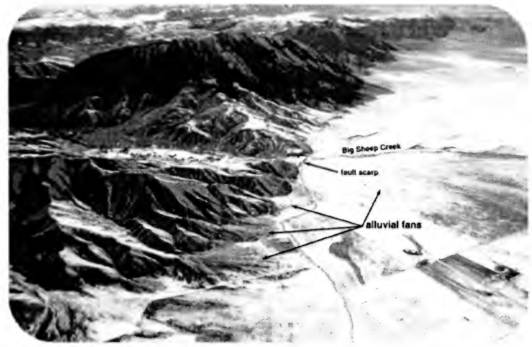
You are looking toward the east at the fault scarp that cuts the pediment bordering the western end of the Centennial Mountains in SW Montana.

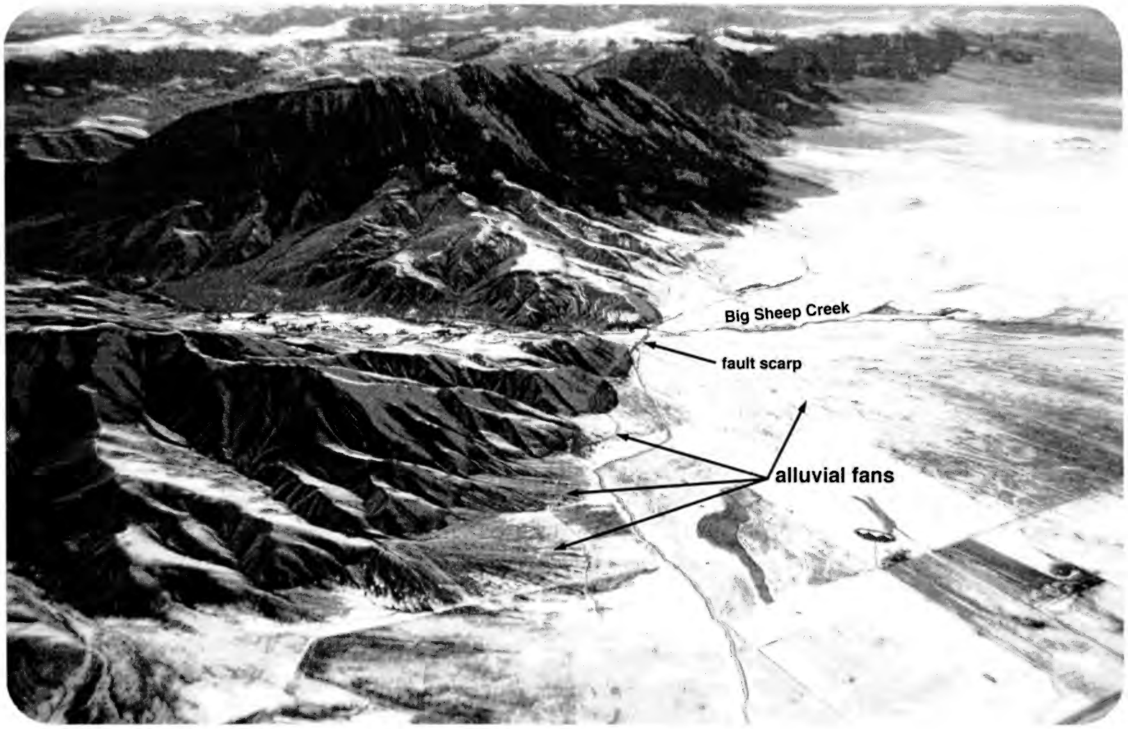


You are looking toward the south at the Red Rocks fault scarp as it cuts across Big Sheep Creek and continues southeastward along the Tendoy Mountain front. As the valley in front of the mountains dropped, the creeks draining the mountains deposited their loads, forming alluvial fans that restored the gradient needed to transport their sediment loads. Mike Stickney and Jerry Bartholomew of the Montana Bureau of Mines and Geology trenched across the fault scarp at Big Sheep Creek. The trench revealed a buried soil A horizon which contained humus that gave a carbon 14 age of 3705 years. Humus from the base of the modern soil A horizon, that buried the older soil after it dropped, gave an age date of 2240 years. Thus, it would appear that the scarp formed about 3000 years ago.*

*Personal communication from Mike Stickney July 9, 1996.



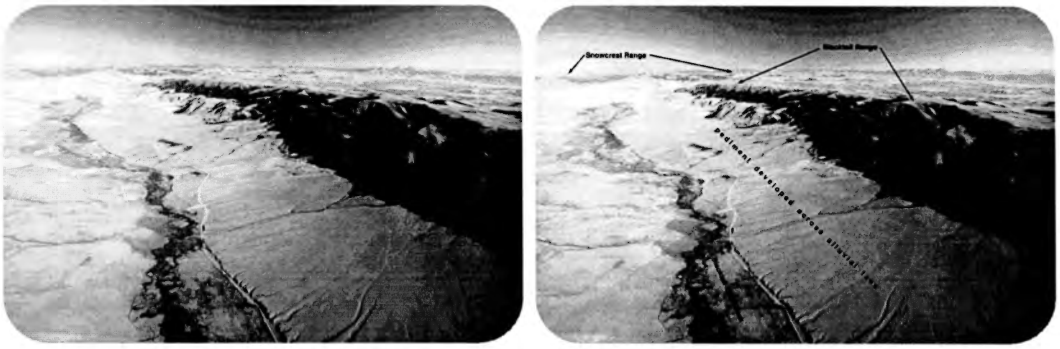


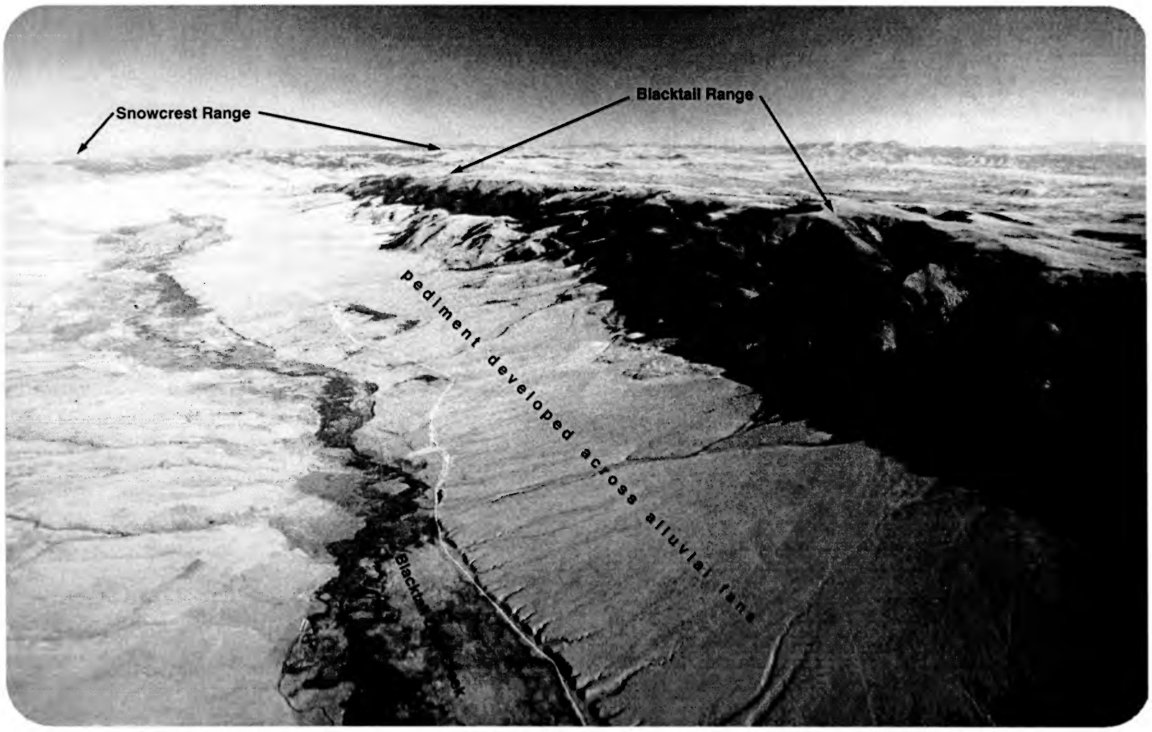


You are looking toward the north at alluvial fans built by creeks that drain the Tendoy Mountains. The creeks drop their sediment to form fans because their gradients are reduced when the mountain-bordering valley drops along the fault. The creeks with larger drainage basins and greater discharge build longer and gentler fans; those with smaller drainage basins and lesser discharge build shorter and steeper fans.

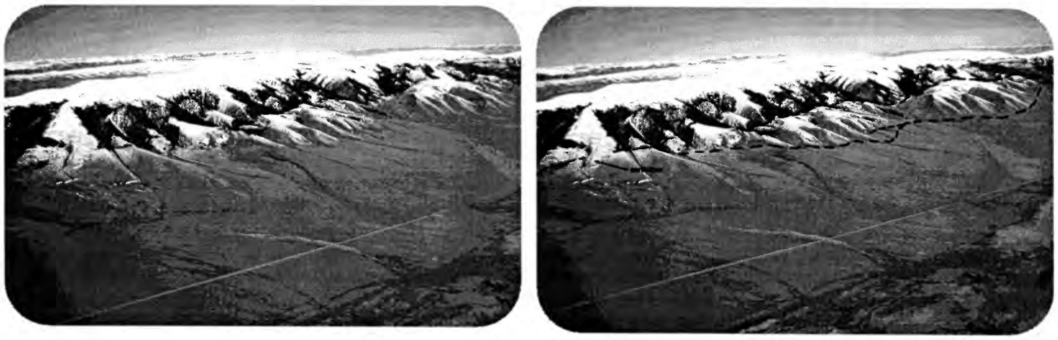
You are looking toward the southwest at the northwest-striking Blacktail, Sweetwater and Stone Creek faults. These are Precambrian faults that were reactivated during the Laramide Orogeny as left reverse faults.* Since the end of that orogeny, they have acted as normal faults.

* Schmidt, C.J. and Garihan, J.M., 1986, "Middle Proterozoic and Laramide Tectonic Activity Along The Southern Margin Of The Belt Basin", Montana Bureau of Mines and Geology Special Report 94, p 227.

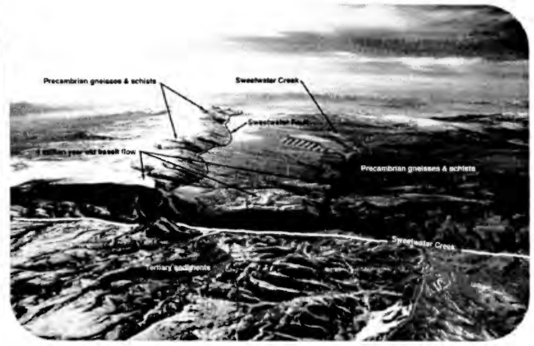


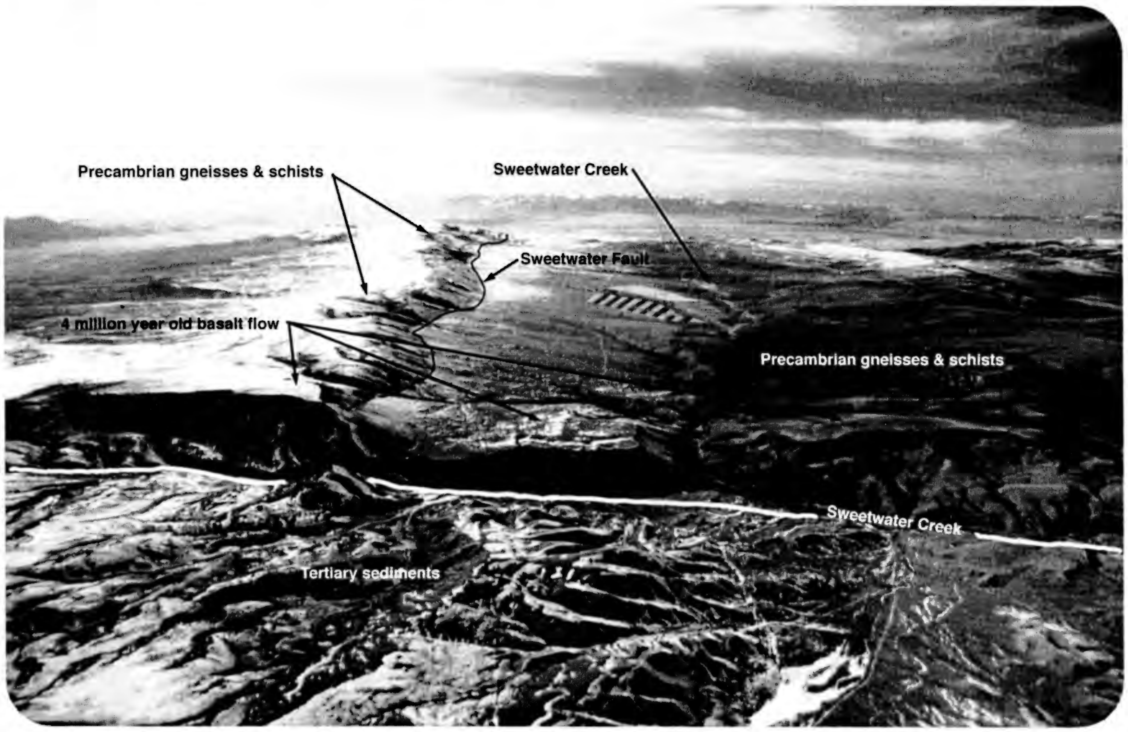


You are looking toward the southeast up Blacktail Deer Creek at the pediment developed along the front of the Blacktail Range. Lines of vegetation along the strike of the pediment surface probably indicate springs aligned along faults.

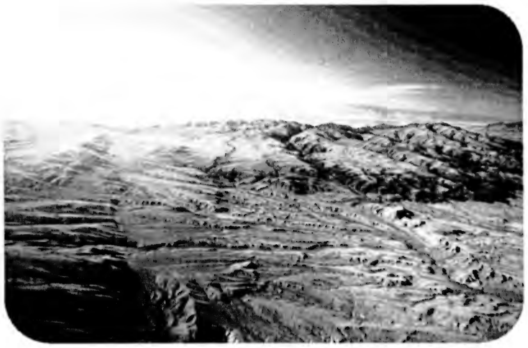


You are looking west at dual fault scarps along the southeast end of the Blacktail Range in southwestern Montana. Faceted spurs and breaks in slope define the two faults. Because the alluvial fans in front of the lower scarp have not been eroded into a pediment as they have to the northwest along this mountain front, the movement on the lower fault has been more recent here, probably since the last interglacial epoch. These fans most likely bury the pediment that formed during that epoch.





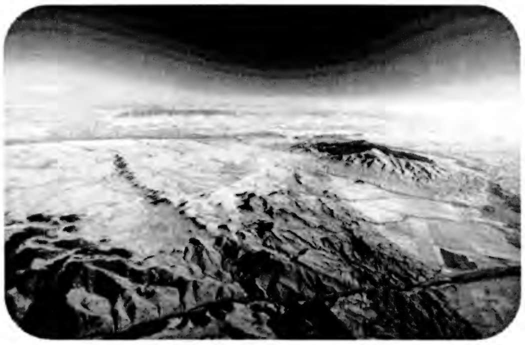
You are looking toward the northwest along the Sweetwater Fault in SW Montana. Sweetwater Creek appears to have been superimposed onto the basalt flow from sediments that buried the flow. It has cut a canyon through the basalt instead of diverting around the north end of the flow. It then makes a right angle bend to flow northeastward along the fault (white line) that truncates the Sweetwater Fault and separates the Tertiary sediment in the foreground from the basalt and Precambrian gneisses and schists in the middle ground.

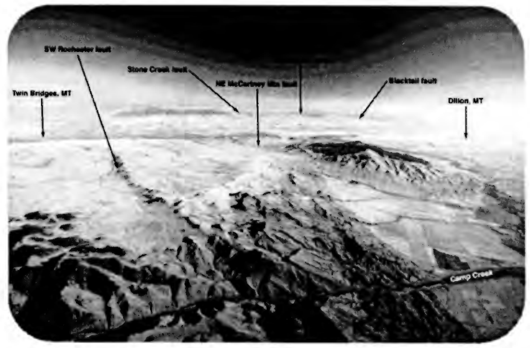


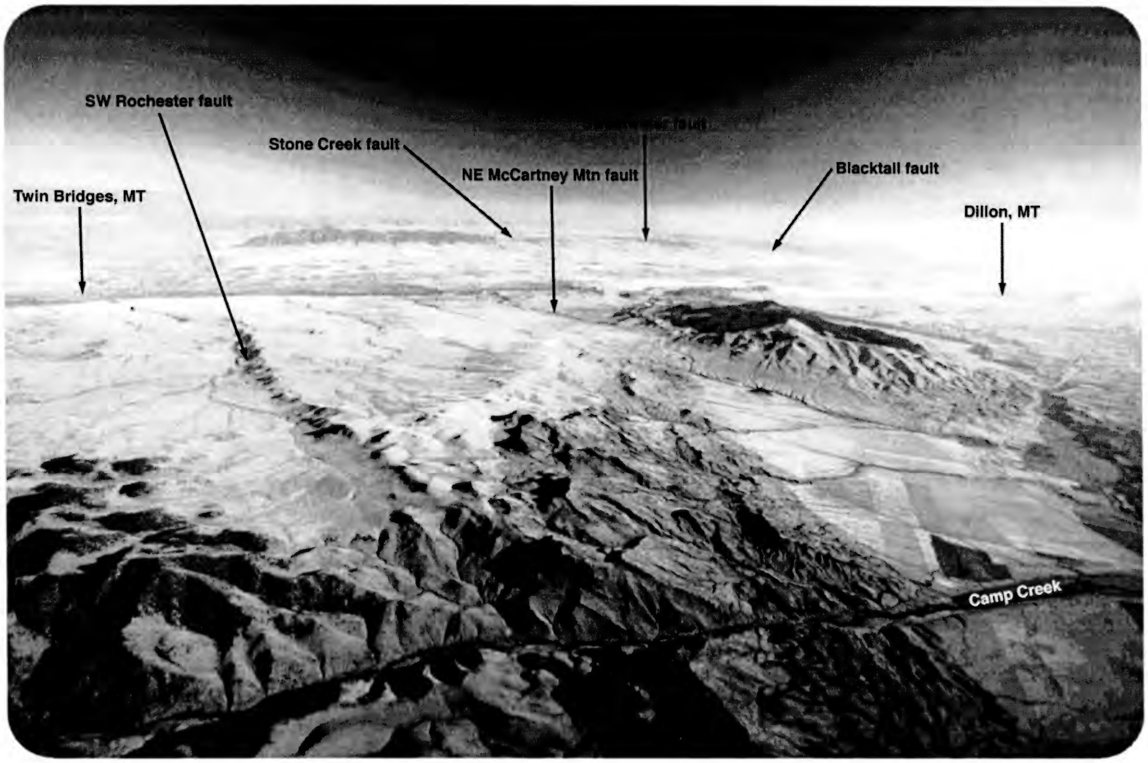
You are looking toward the northwest along the Stone Creek Fault, a Precambrian fault reactivated during the Laramide Orogeny as a left reverse fault and during the Cenozoic as a normal fault. It separates the northern Ruby Mountains from the middle Ruby Mountains. Diabase dikes along some of the NW-trending faults that cut the Ruby Mountains have been dated as 1.45 billion years old.*

PC = Precambrian gneiss and schist.
Ts = Tertiary sediments

*Wooden, J.L. and others, 1978 as cited in Garihan, J.M. 1979, "Geology and structure of the central Ruby Range, Madison County, Montana: Summary" GSA Bulletin vol 79, Part 1, April, 1979, pg. 325.





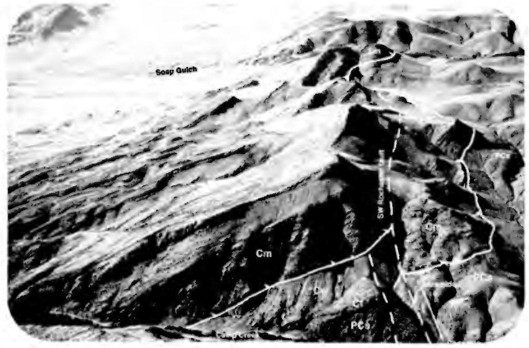


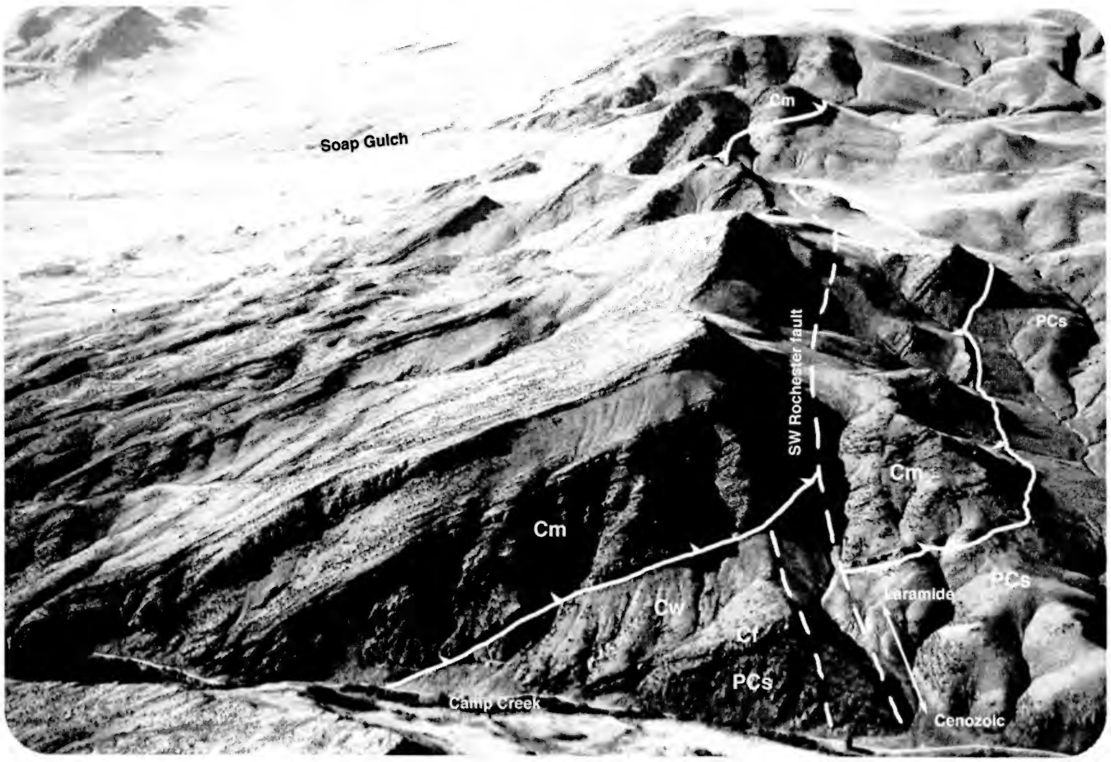
You are looking toward the southeast along the SW Rochester fault. Five northwest-striking, northeast-dipping Precambrian faults can be seen.

During the Laramide Orogeny, when this terrane was crumpled from west to east, these faults acted as left reverse faults. That is, their northeast sides rose and slid northwest.* Several of the faults subdivided the crust into blocks, each of which deformed in a unique style during the mountain building orogeny. For instance, the strata in the Camp Creek block strike northwest, dip southwest and are cut by folded thrusts. Between the NE McCarthey Mountain fault and the Stone Creek fault, the beds strike northeast and are folded into northeast-plunging structures that are cut by step thrusts.

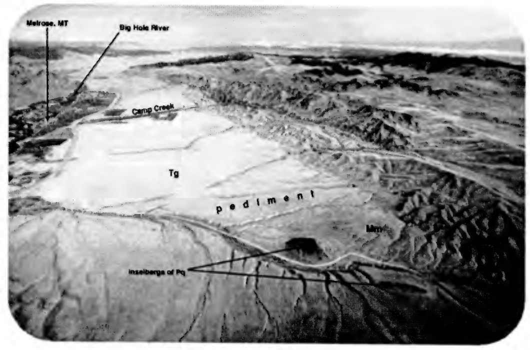
During the Cenozoic, as this terrane stretched from east to west, these Precambrian faults acted as normal faults.

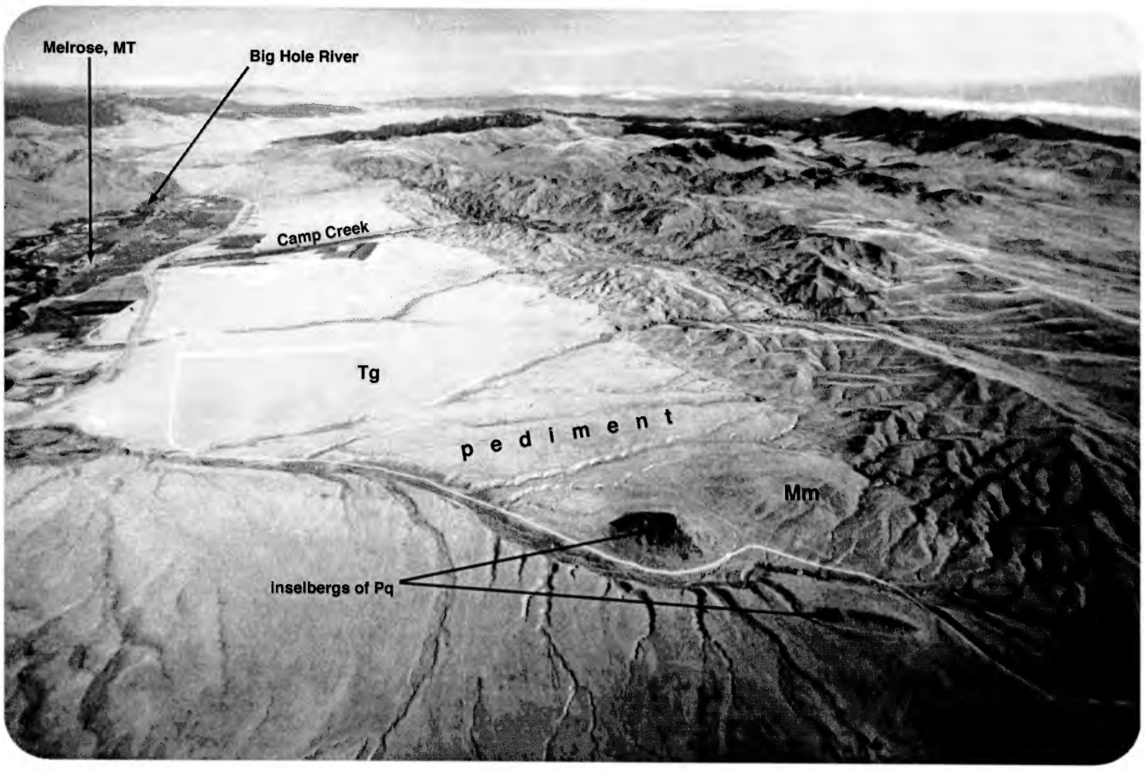
* Schmidt, C.J. and Garihan, J.M., 1986, “Middle Proterozoic and Laramide Activity Along The Southern Margin Of The Belt Basin”, Montana Bureau of Mines and Geology Special Report 94, p227.



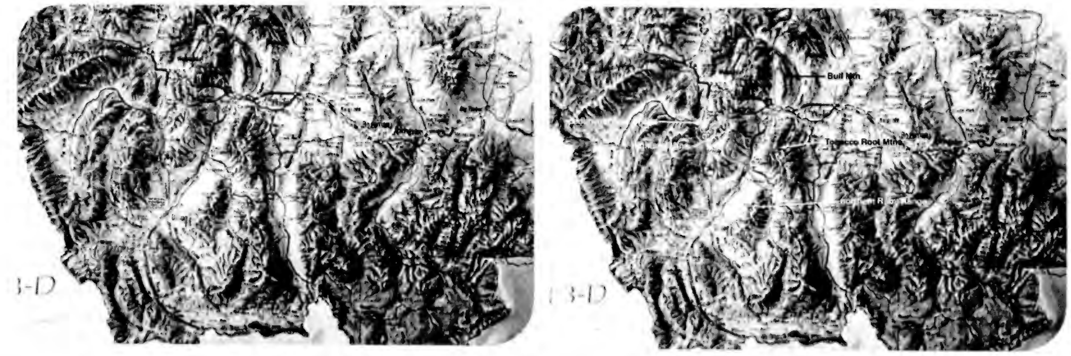


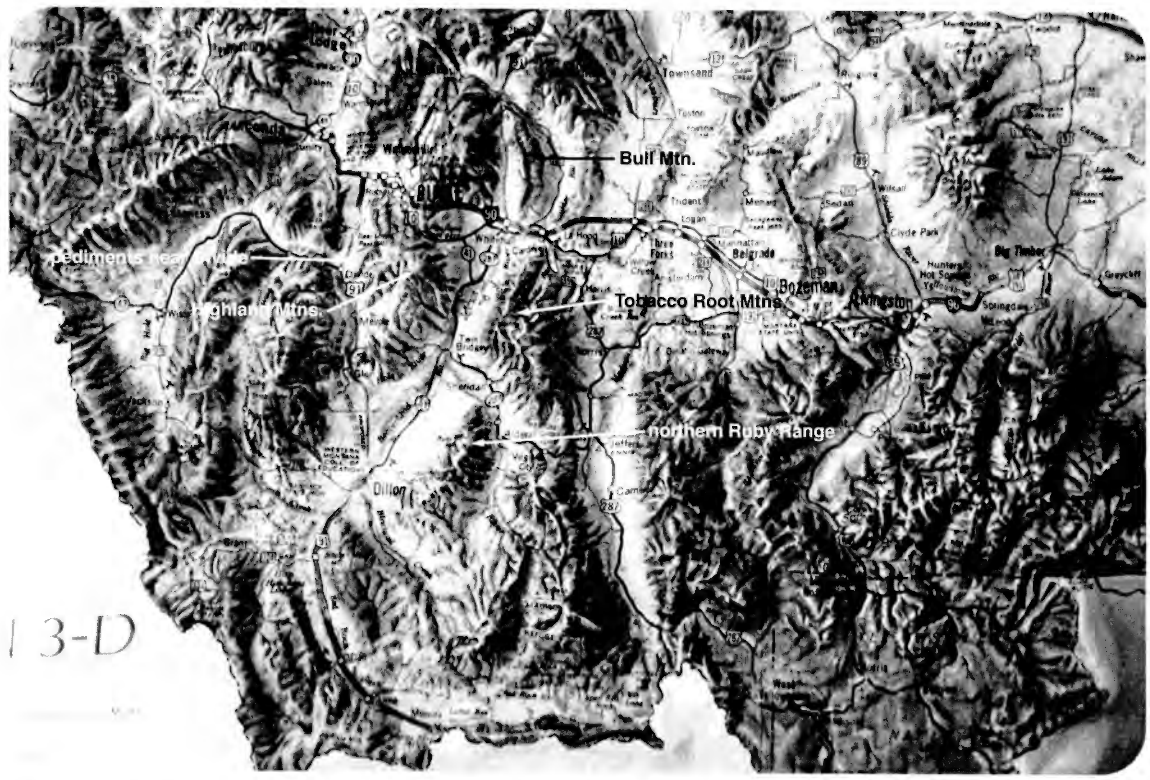
You are looking northwest across Camp Creek along the SW Rochester fault. During the Laramide west-to-east compression, its northeast side rose placing the PCs (Precambrian schist) opposite the Cm (Cambrian Meagher dolomite). The Cm then thrust northeastward along its contact with the Cw (Cambrian Wolsey shale) across the SW Rochester fault to slide the dolomite onto the Precambrian schist. Cf is the Cambrian Flathead sandstone. During the Cenozoic, the SW Rochester fault became a normal fault, dropping its northeast side back side down.





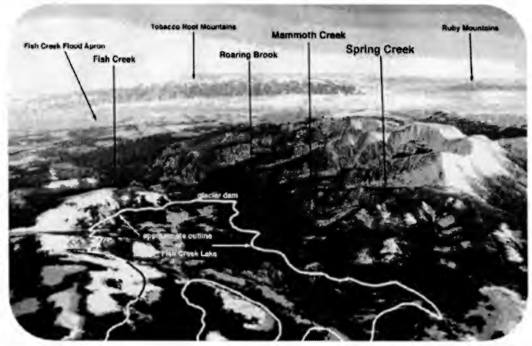
You are looking toward the north at the pediment on the east side of the Big Hole River near Melrose in southwestern Montana. The pediment extends from Tertiary gravels (Tg) onto the Mississippian Madison limestone (Mm). Inselbergs of Pennsylvanian Quadrant quartzite (Pq) are erosional remnants of the pre-pediment topography. The Tertiary gravels filled this basin as it dropped along faults on its eastern side. Those faults could be late Cretaceous thrust faults reactivated as normal faults in the Tertiary.

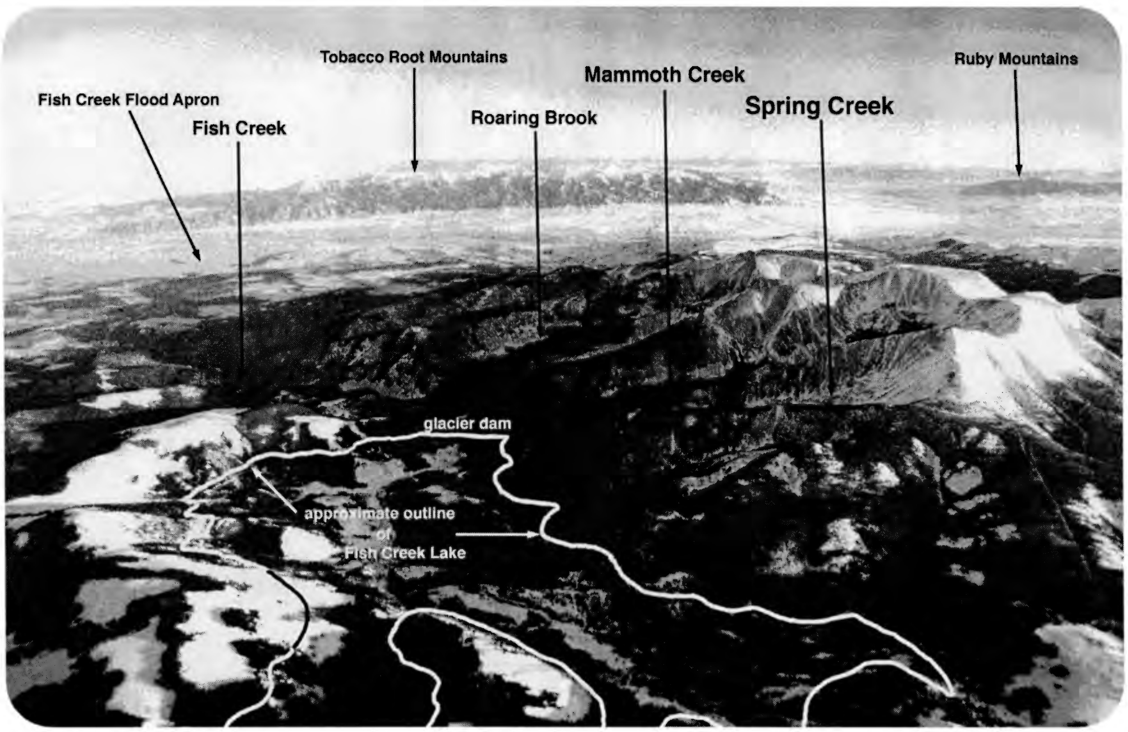




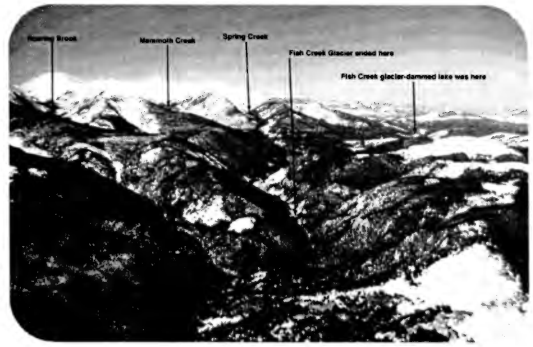
Index map showing the locations of the features shown on the next 24 pages.

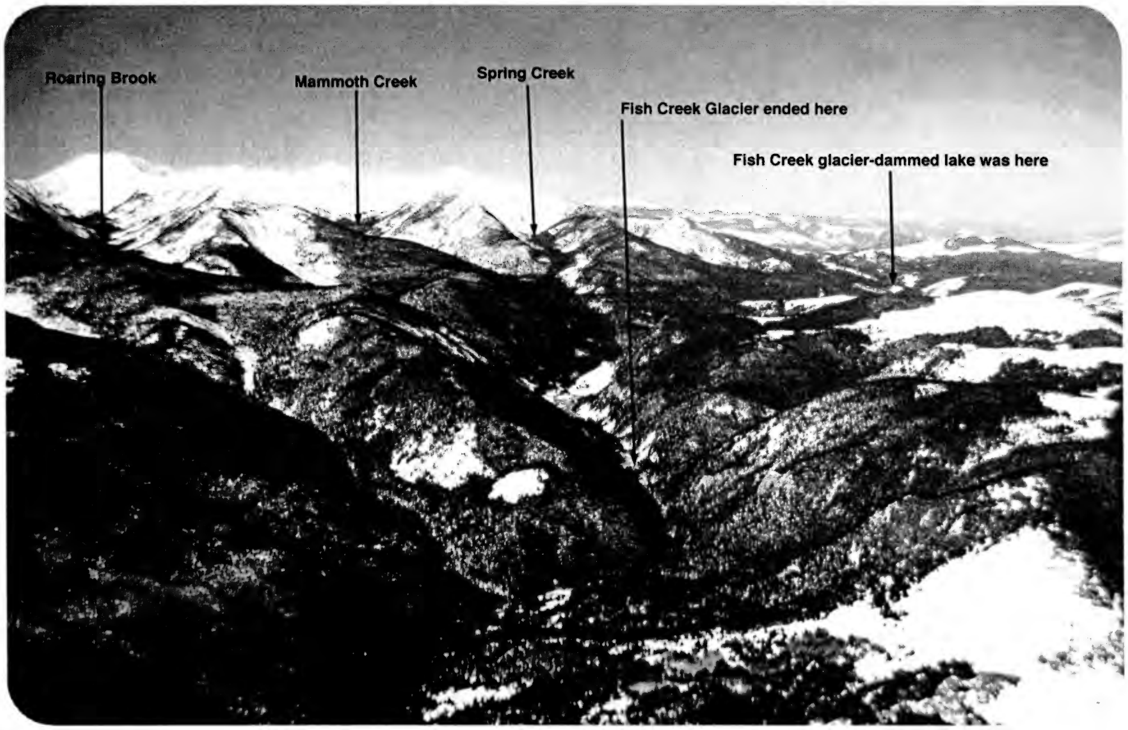
You are looking toward the north at the pediments in the Rocker-Divide Valley. The Tertiary sediments in the valley dip toward the east because they have been dropped along the fault that borders the east side of the valley. The pediments are erosional surfaces that cut across the tilted beds.



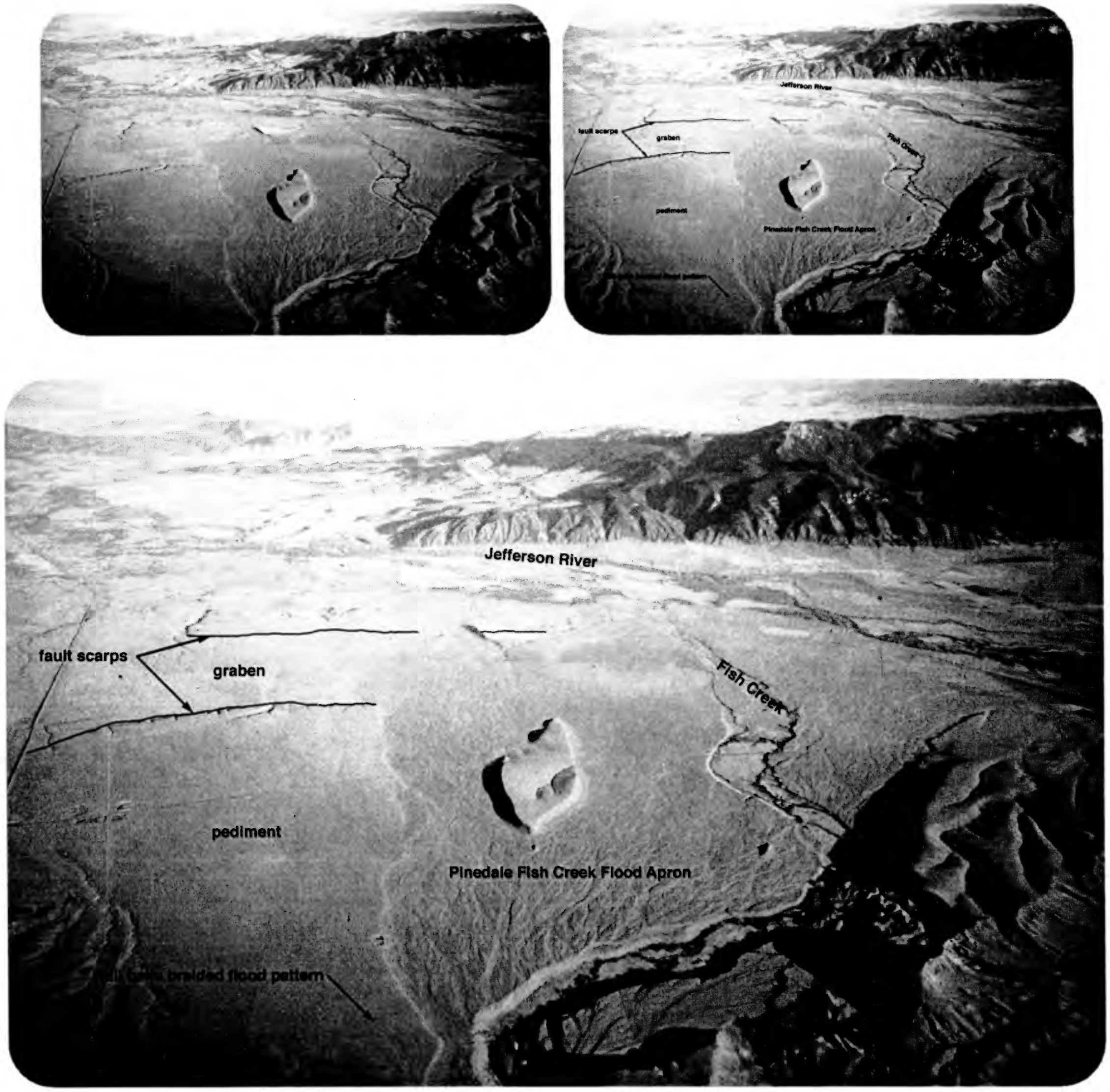


You are looking toward the east at the headwaters of Fish Creek in the Highland Mountains south of Butte, Montana. Glaciers in Spring Creek, Mammoth Creek, and Roaring Brook joined to form a glacier in the middle part of Fish Creek. The headwaters of Fish Creek, too low to support a glacier, were dammed to form a lake. When the glacier dam failed, outburst flood waters from Fish Creek Lake rushed down the valley, washed out the terminal moraine, and deposited huge boulders and cobbles in a braided pattern on the Fish Creek Flood Apron in the Jefferson River Valley. That this happened more than once during the Pinedale glaciation, which reached its maximum about 18,000 years ago, is indicated by several levels of outburst flood deposits on the flood apron.

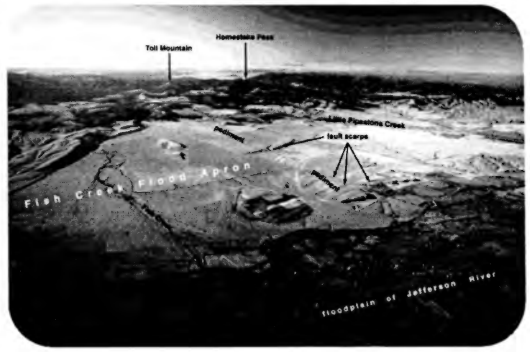


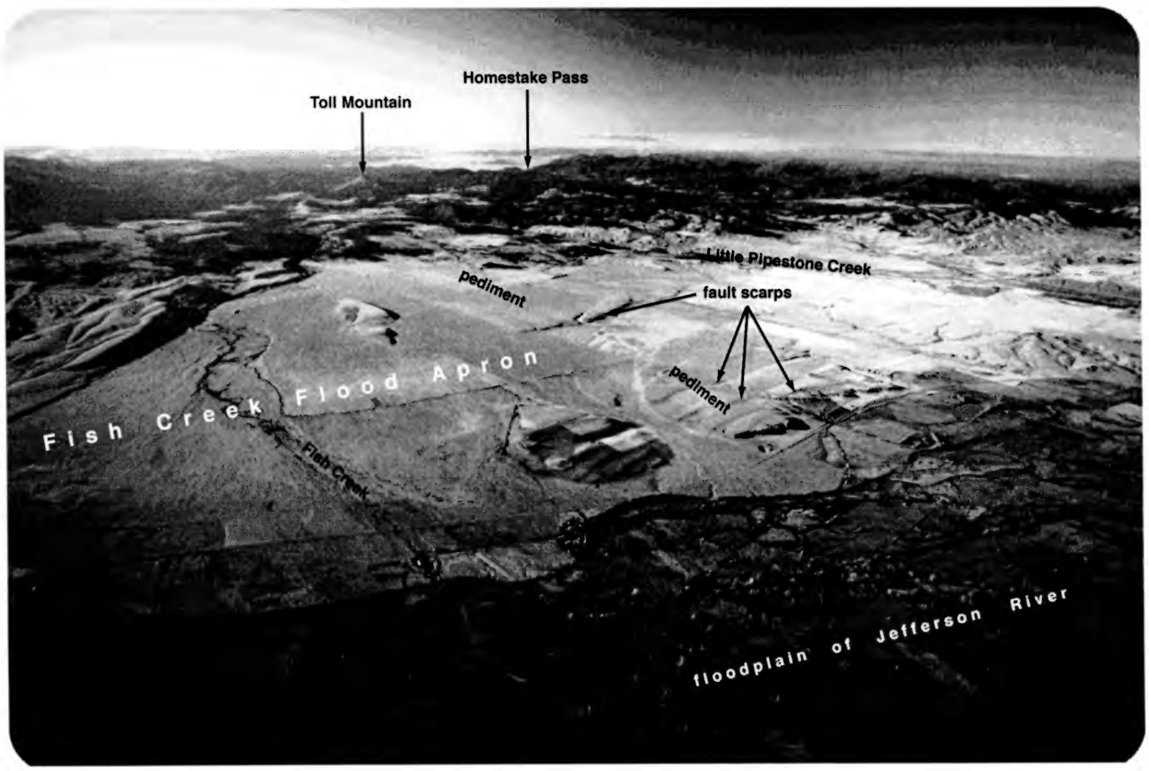


You are looking toward the west up Fish Creek at the Highland Mountains south of Butte, Montana. Glaciers in Roaring Brook, Mammoth Creek and Spring Creek joined to form a glacier in Fish Creek. This glacier dammed the headwaters of Fish Creek. When the dam failed, chunks of glacier ice and water from the lake rushed down Fish Creek, ripped out the rocks and debris that had accumulated at the snout of the glacier, washed on down the canyon, and deposited the rocks and debris as a braided flash flood apron where the waters spread out in the Jefferson Valley.

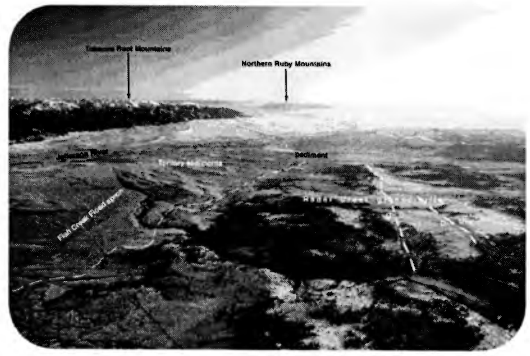


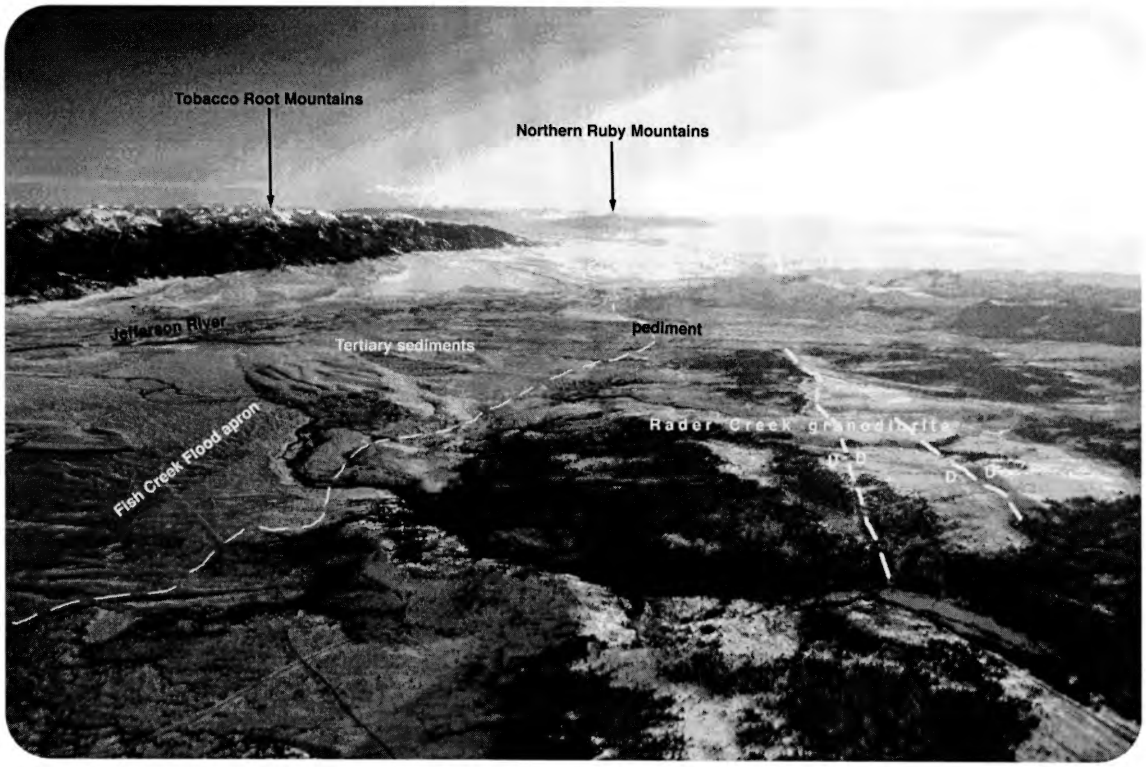
You are looking toward the east at the prominent braided flood apron left by outburst floods of Pinedale-age glaciers (about 16,000 years ago). An arrow points to the dimly-visible braided pattern left by outburst floods from Bull Lake-age glaciers (about 120,000 years ago). A pediment surface developed on the Bull Lake outburst flood deposits during the arid interval between the glaciations. This pediment surface dropped along faults to form a graben before the Pinedale-age outburst floods washed across it.



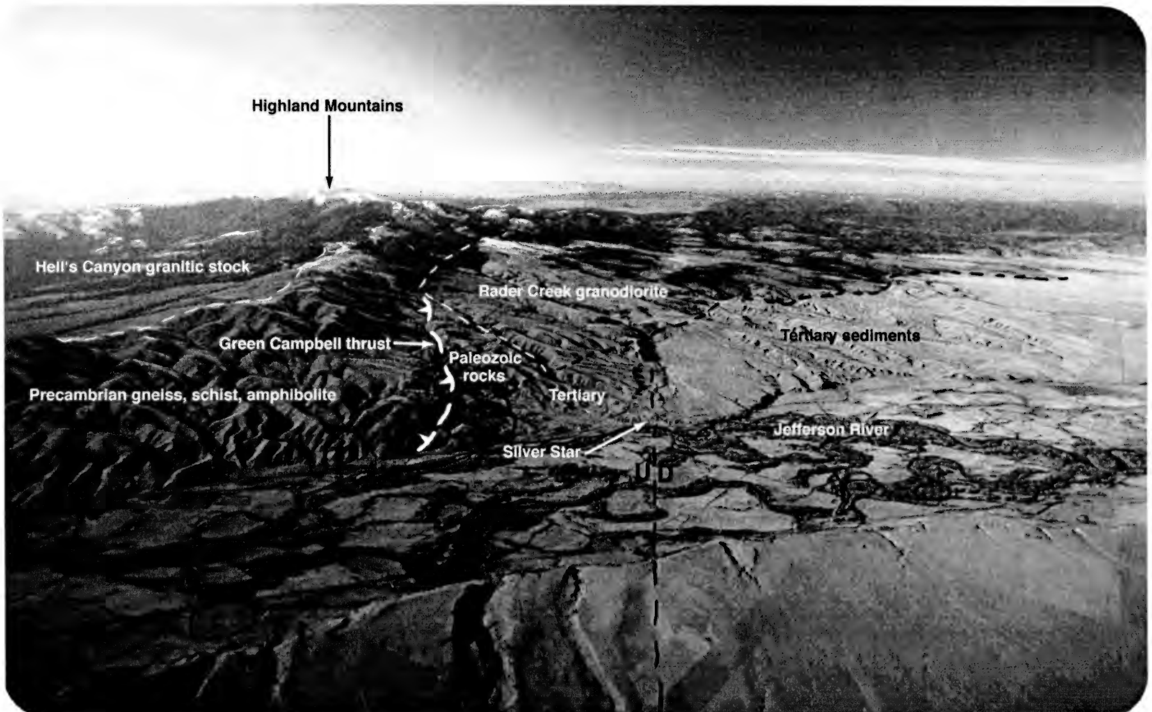


You are looking northwest at the braided apron of bouldery gravel transported by the Fish Creek outburst floods, probably less than 16,000 years ago, near the end of the Pinedale glaciation. The pediment surface is developed on similar bouldery gravel probably deposited by outburst floods near the end of the Bull Lake glaciation, about 120,000 years ago. The pediment surface, then, developed during the interglacial period centered about 70,000 years ago. The pediment has been offset by fault scarps which are truncated by the deposits of the Pinedale Fish Creek floods.

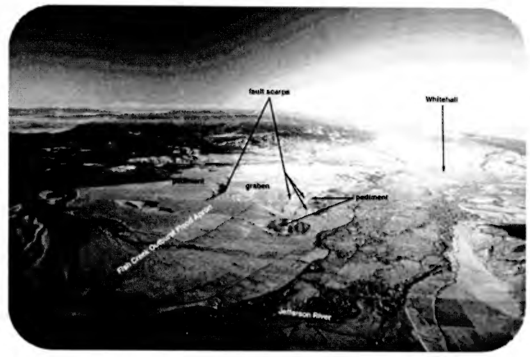


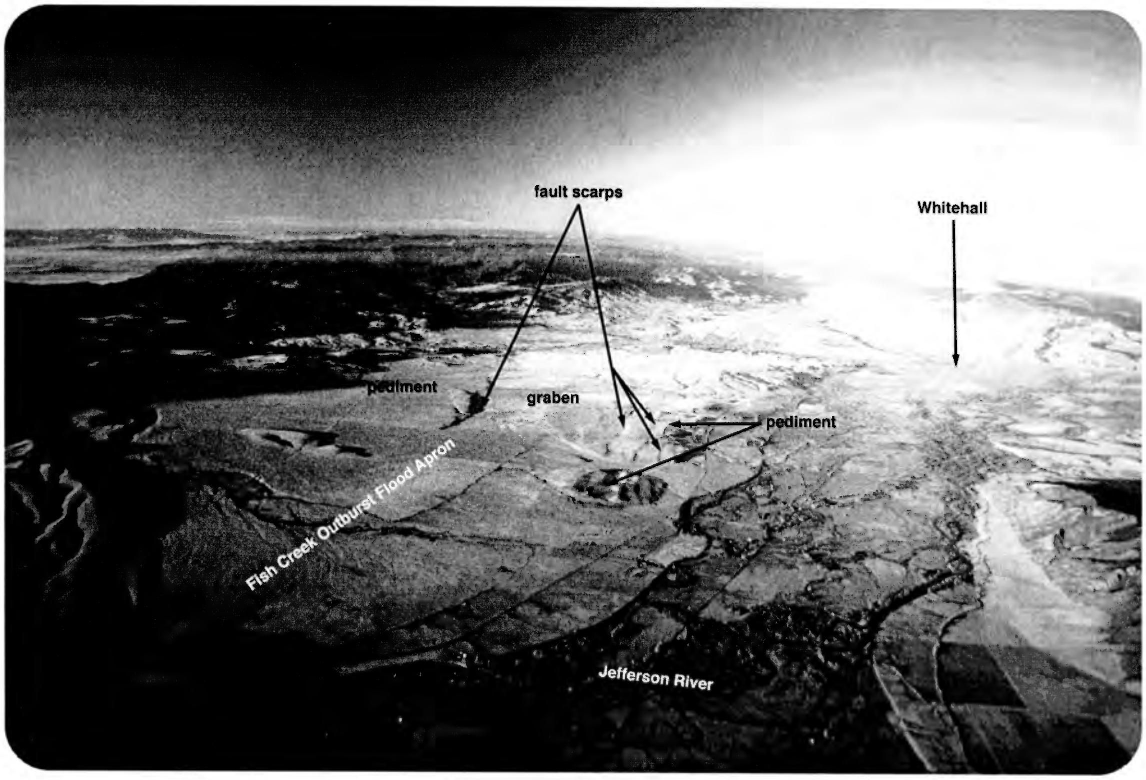


You are looking south at the pediment on the east side of The Highlands. Where the word "pediment" is written, the pediment extends unbroken from the Rader Creek granodiorite onto the Tertiary sediments. In the foreground the pediment is disrupted by normal faults.

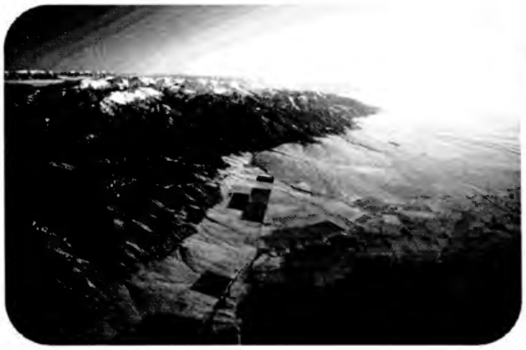


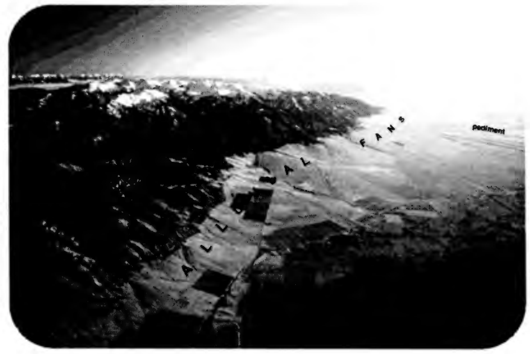
You are looking across the Jefferson River Valley toward the northwest at the sloping surface (pediment) on the eastern side of the valley. The pediment is well developed across the Rader Creek granodiorite and onto the Tertiary sediments. Another pediment is well developed on the Hell's Canyon granitic stock. These pediments are arid landforms that developed during the dry intervals between glaciations. They formed quickly across soft Tertiary sediments and across granitic rocks when the climate changed from humid to arid following a period of glaciation. Deep weathering during the humid glacial intervals prepared the soil for sheetwash and rillwash erosion during thunderstorms in the arid interglacial intervals. The change in climate produced wildfires and droughts that killed the sediment-anchoring, humid-era vegetation. The Tertiary sediments and granitic rocks had weathered into sand that was easily eroded and transported by sheetwash and rillwash down the interstream slopes until the water sank into the parched surface, leaving a veneer of sandy sediment. Repetition of this process filled the slightly low spots and eroded the high spots, producing a smooth, inclined surface, a pediment. The pediments were not graded to the creeks because the creeks were incised through them, and much of the sheetwash and rillwash never reached the creeks. When the climate changed back to humid during a glacial episode, vegetation anchored the pediment surface and downwasting virtually ceased. Erosion then concentrated on reducing the area of the pediment by attacking it from the sides adjacent to the through-flowing, incised drainages. Following the Pinedale glaciation, which reached its maximum about 18,000 years ago, the area is now in the process of changing from humid to arid.

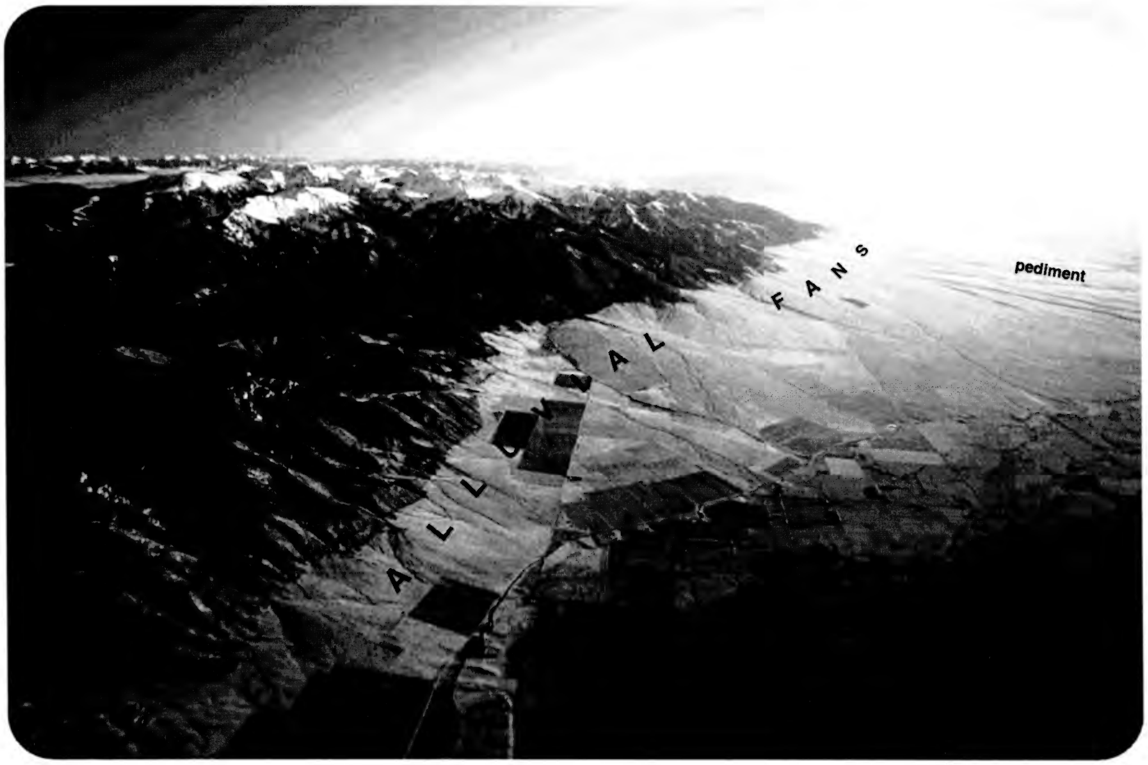




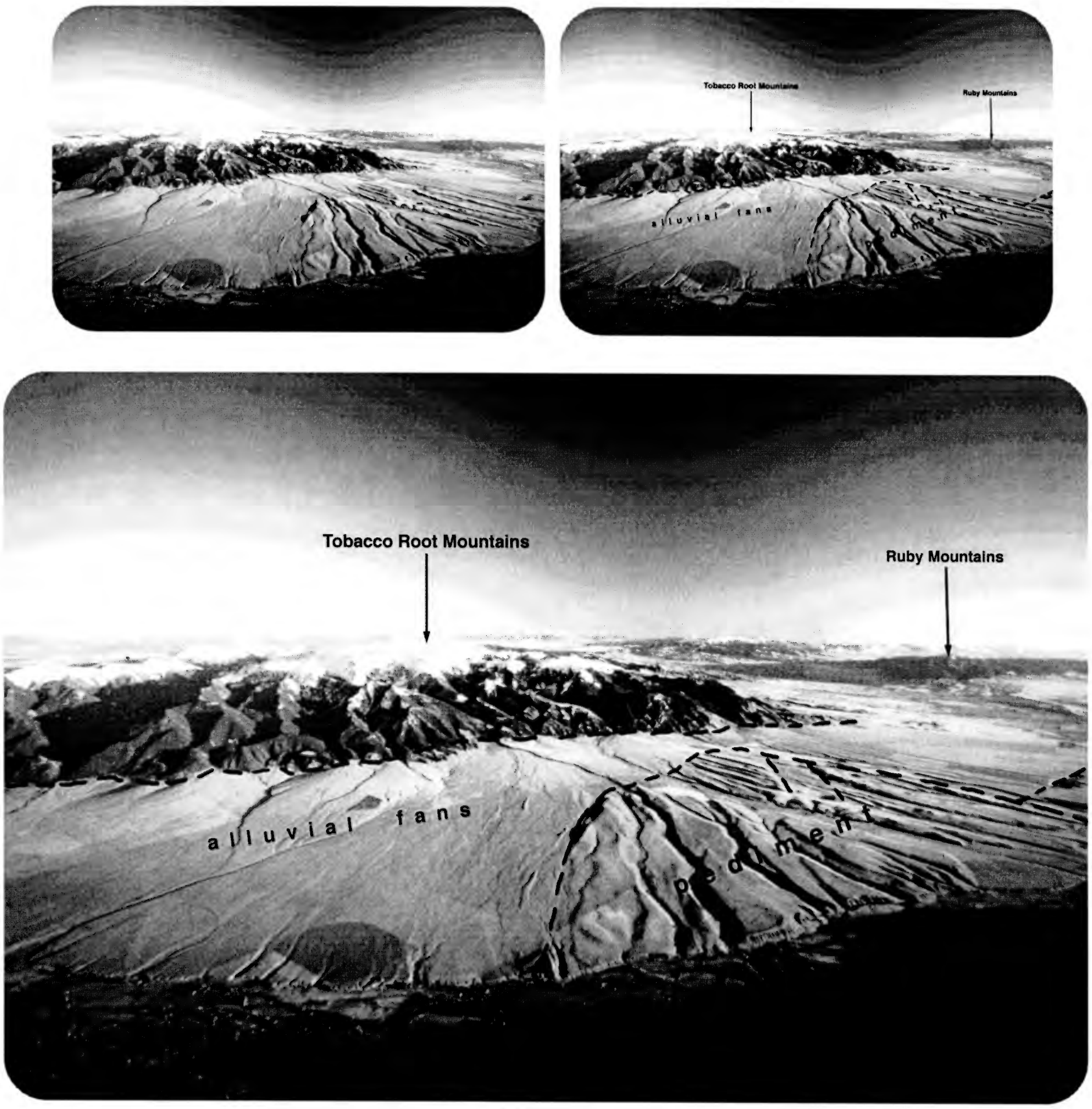
You are looking northward down the Jefferson River at pediments cut by faults on the western side of the valley. About 16,000 years ago the Fish Creek outburst floods deposited an apron of coarse gravel that cuts across the fault scarps.



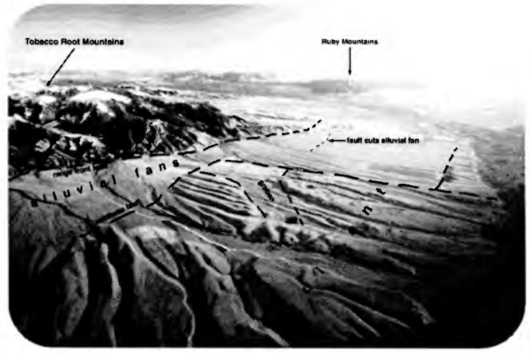


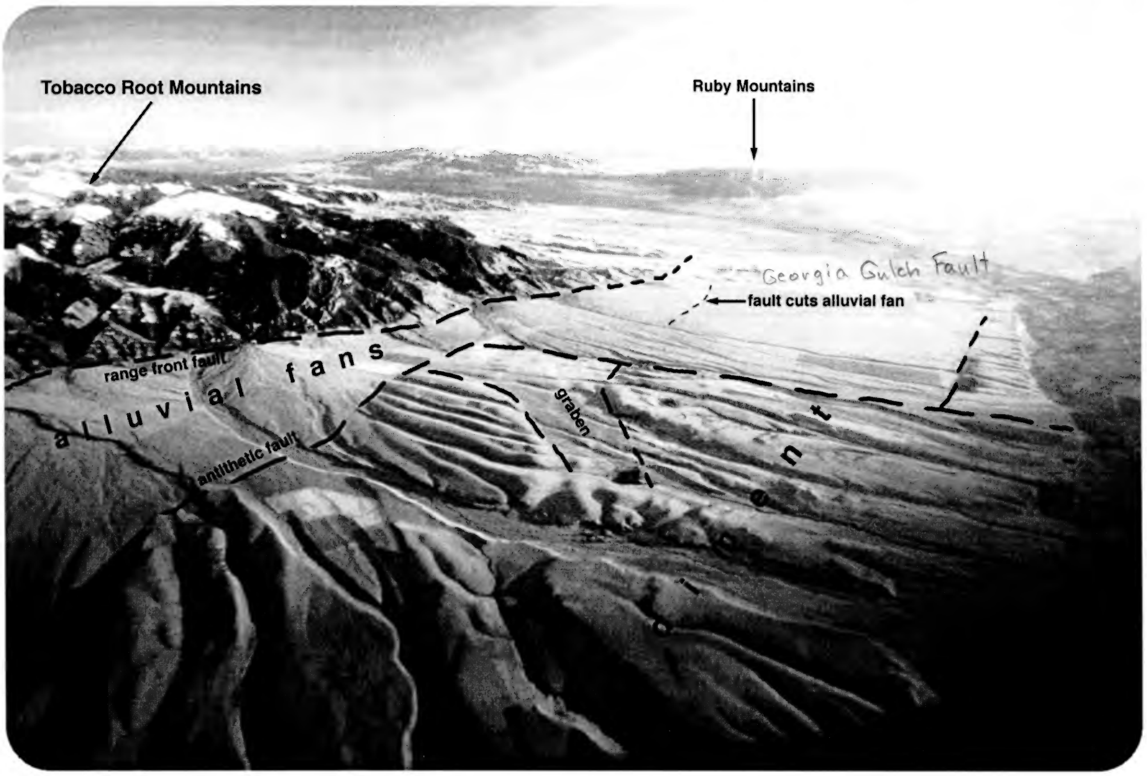


You are looking south at the alluvial fans along the western side of the Tobacco Root Mountains. The alluvial fans bury most of the pediment surface, but a remnant of it is exposed in a horst in the middle of the Jefferson Valley. Because the last episode of pediment development took place during the last interglacial interval, centered about 70,000 years ago, the fault along the mountain front has dropped the valley since that time. The streams then no longer had sufficient gradients to transport their loads to the Jefferson River. They dropped the coarsest material closest to the mountain and finer materials farther out to form the alluvial fans that bury the pediment.

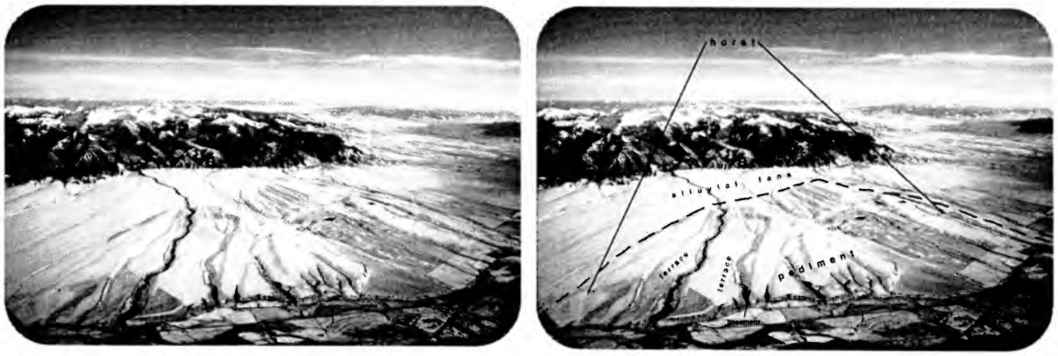


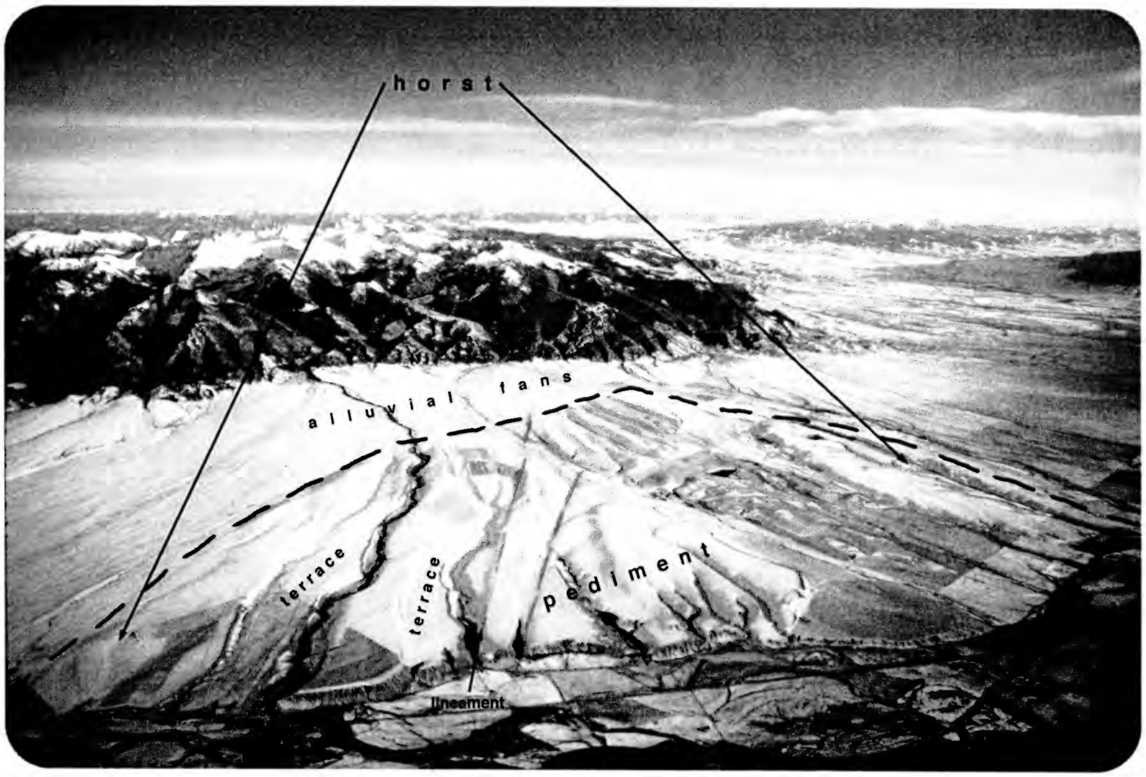
You are looking southeastward at a dissected pediment surface preserved in a horst in the Jefferson Valley. Alluvial fans bury the pediment along the mountain front. Dashed lines follow faults. Because the last episode of pediment formation took place during the arid climate between the Bull Lake and Pinedale glaciations, about 70,000 years ago, the last fault movements and the fans must postdate that episode.





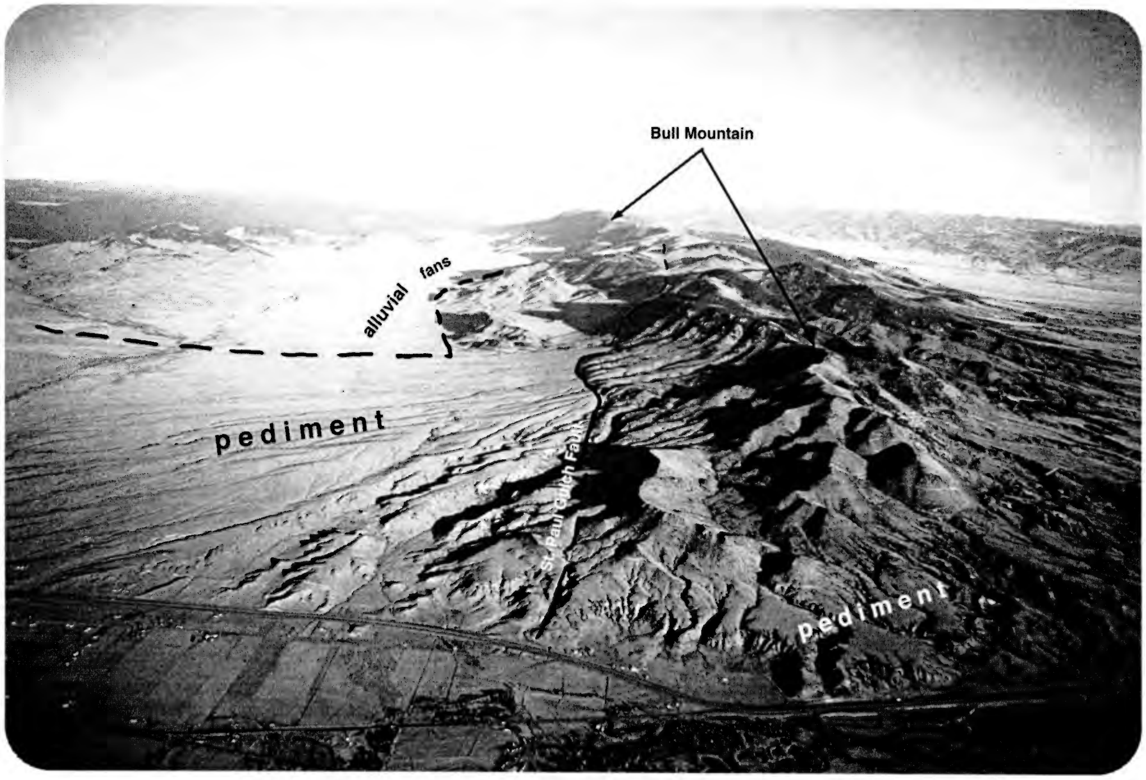
You are looking southward. A small graben cuts the dissected pediment surface within the Jefferson Valley horst. Alluvial fans along the mountain front bury the pediment in the graben dropped between the range front fault and its antithetic fault. The most recent fault cuts the alluvial fan in the distance



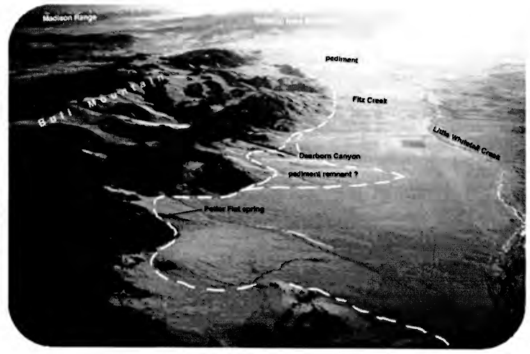


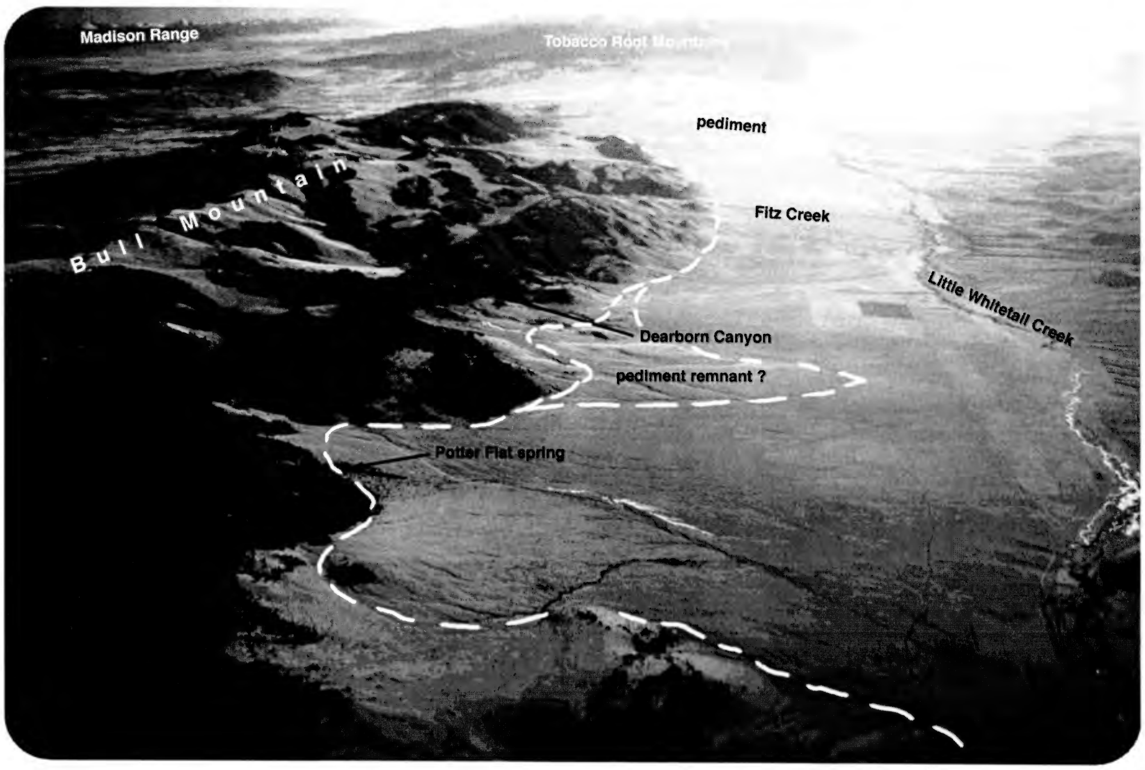
You are looking southeastward at the pediment surface on the horst in the Tobacco Root bajada. The horst has remained high while the ground around it dropped along the faults. Alluvial fans then filled in these low areas. If the lineament is a fault, its last movement is older than the pediment, for it has not offset the pediment. The terraces are restricted to the horst, and they probably were the stream bottoms while pediments were forming on the adjacent interfluves during the Bull Lake - Pinedale interglacial interval about 70,000 years ago. Since then, the Jefferson River has cut downward and its tributary streams have incised below their old valley bottoms, leaving them as terraces. The width of the terraced valley of the stream adjacent to the lineament indicates that it was a major mountain-draining stream during the last interglacial interval. Its headwaters have been captured since then by the next major drainage to the south. That drainage flows more directly down the slope of the bajada.

You are looking toward the north at the Goodrich Gulch alluvial fan along the western side of the Tobacco Root Mountains in southwestern Montana. The fan is offset by a fault scarp, the most recent scarp in the Jefferson Valley. The line of springs probably also defines a fault, one that causes groundwater to rise to the surface. The pediment is preserved in the horst; whereas, alluvial fans bury it elsewhere. Picture taken 3-2-81.

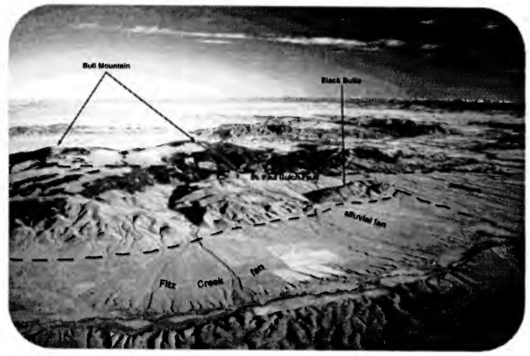


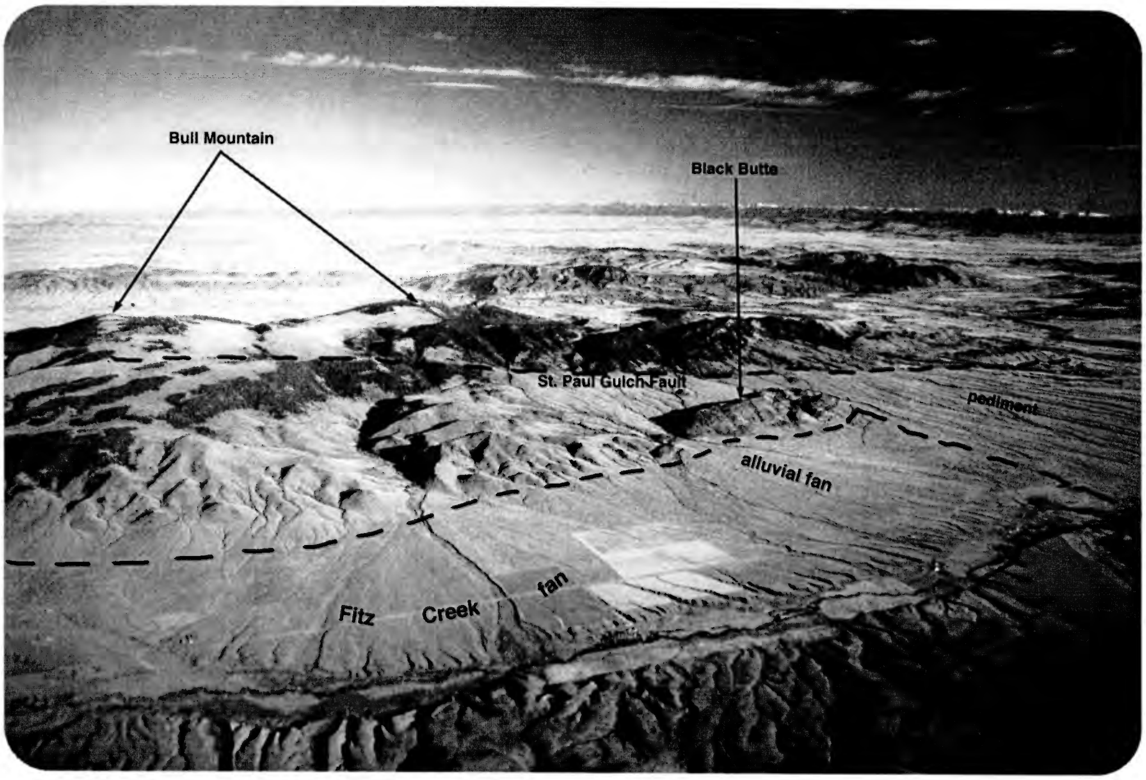
You are looking northward at the south end of Bull Mountain northeast of Whitehall, Montana. Pediments wrap around the end of the mountain. To the north on the west side of Bull Mountain alluvial fans bury the pediment. The block containing the fans dropped after the last episode of pediment formation during the arid interval between the Bull Lake and Pinedale glaciations.



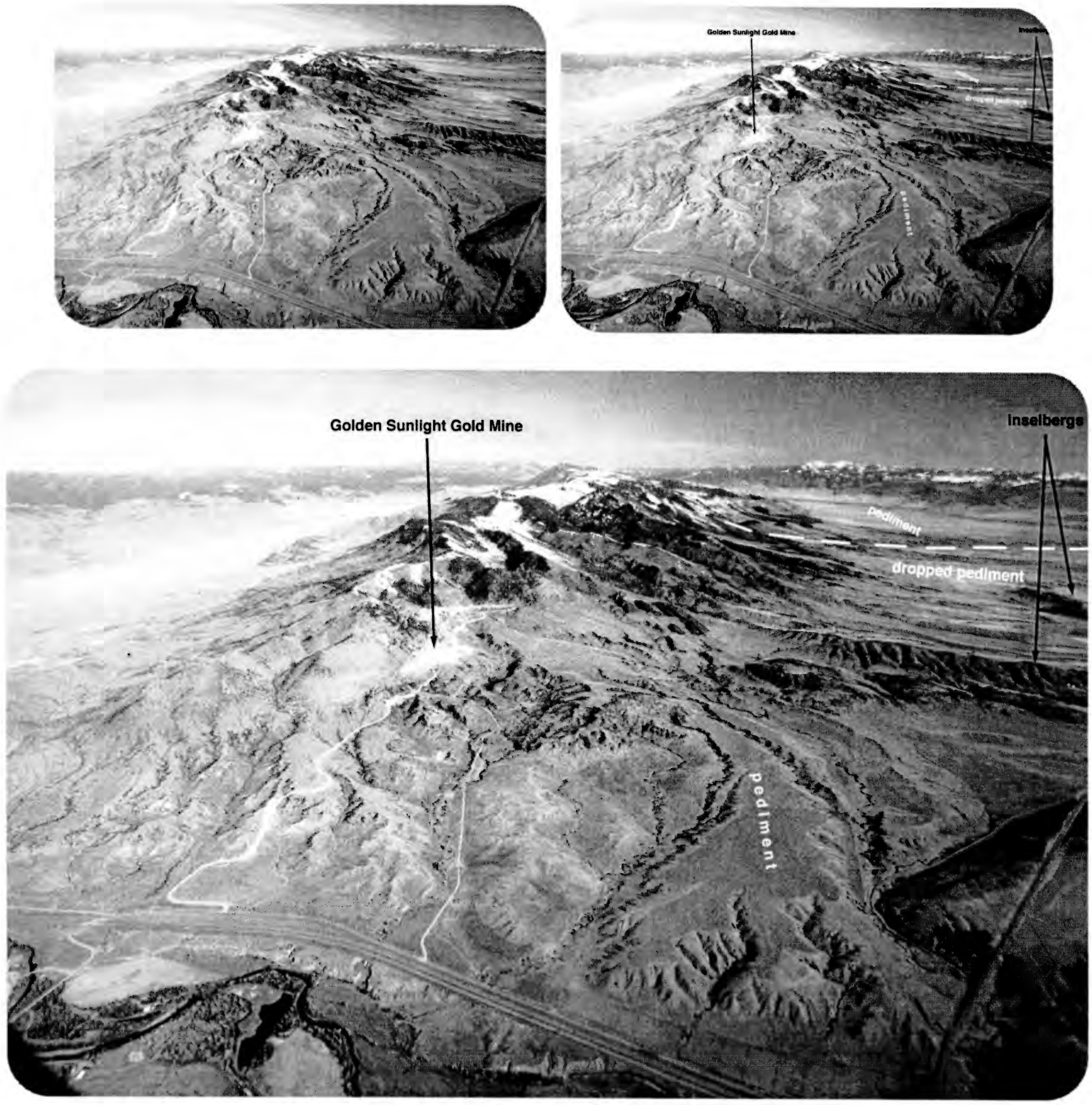


You are looking toward the south at the alluvial fans on the west side of Bull Mountain in southwestern Montana. The white dashed lines are interpretations of the positions of the faults. These alluvial fans bury the pediment that wraps around the south end of Bull Mountain except opposite the mouth of Dearborn Canyon. If this is a remnant of the pediment, then it has been excluded from the latest fault movement. Cross-valley faults may have controlled this odd fault geometry. Picture taken 1-19-81.

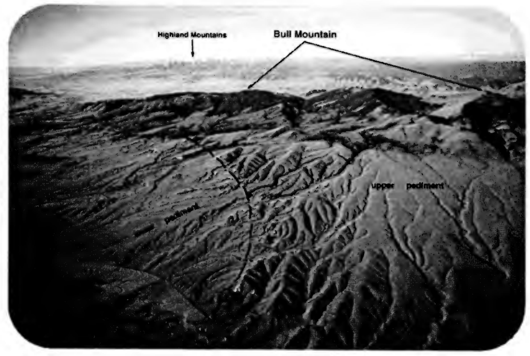


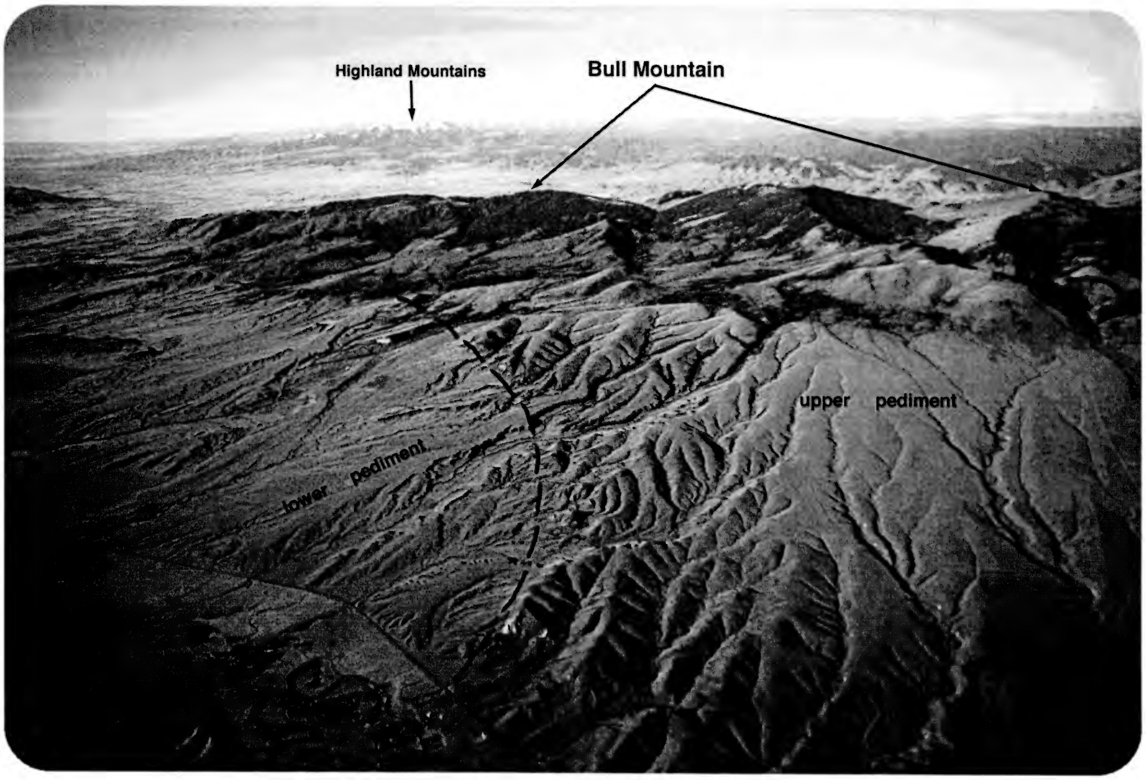


You are looking toward the east southeast. The pediment is buried under the alluvial fans bordering the west side of Bull Mountain. A corner of the dropped block is formed by the intersection of two faults at the south end of Black Butte. The Fitz Creek fan surface is younger and lower on the north half of the fan, older and higher with better developed soil on the south half of the fan. It is the only fan along the west side of Bull Mountain to show this dichotomy. Could a local flash flood have eroded the north half of the fan?

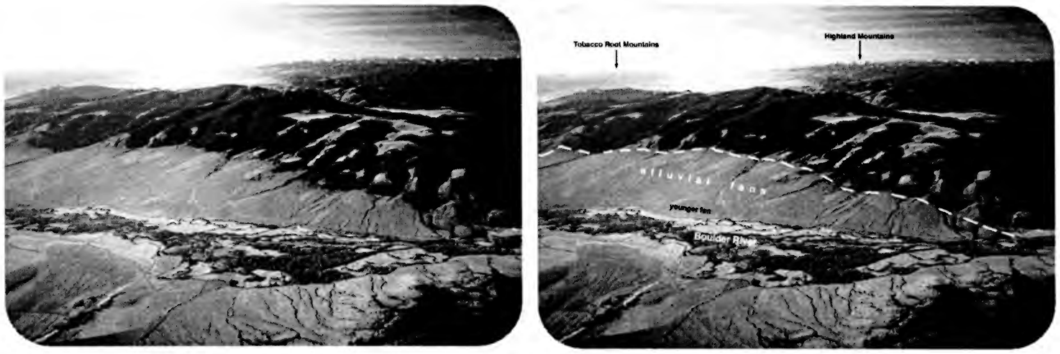


You are looking toward the north at the pediment that wraps around the southern end of Bull Mountain east of Whitehall, Montana. The pediment is best developed on Tertiary sediments, but it extends onto the Precambrian Lahood sandstones and shales at the Golden Sunlight Mine and around the southern end of the mountain. Inselbergs of Paleozoic sedimentary rocks interrupt the pediment south of the fault (dashed line). Picture taken 4-22-82.

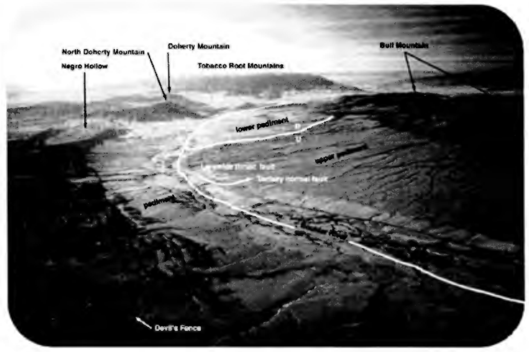


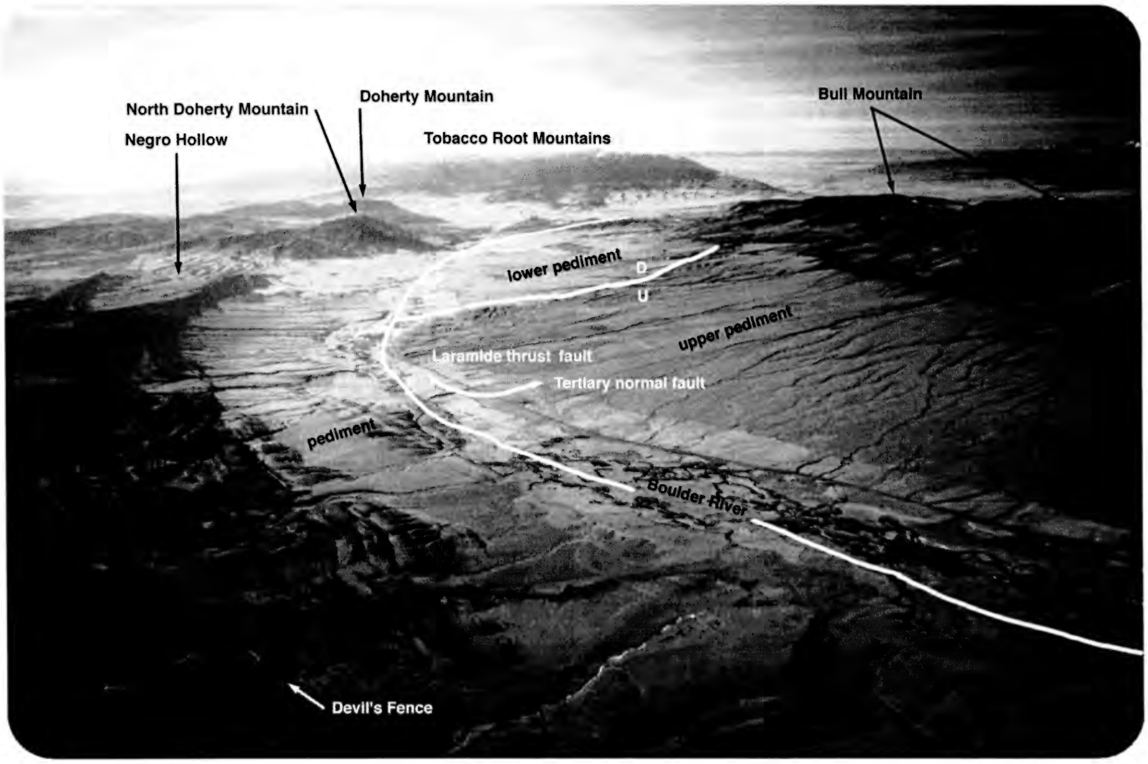


You are looking toward the southwest at the faulted pediment on the east side of Bull Mountain. Because the lower pediment expanded headward into the upper pediment during the last interglacial arid interval, the fault displacement must have occurred before that interval.



You are looking toward the southwest at alluvial fans on the northeast side of Bull Mountain. This segment of the range-front fault dropped the pediment that had formed along the mountain front during the arid climate of the last interglacial interval. Alluvial fans then buried the pediment. Since then, the Boulder River has continued to cut down, causing its tributary creeks to incise into their alluvial fans and to build younger fans out onto its floodplain. The time required to accomplish this probably indicates that this faulting occurred late in the last interglacial interval.

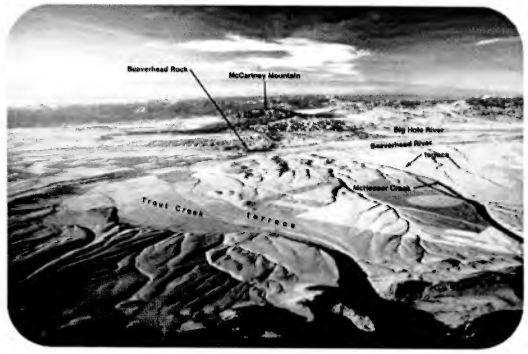


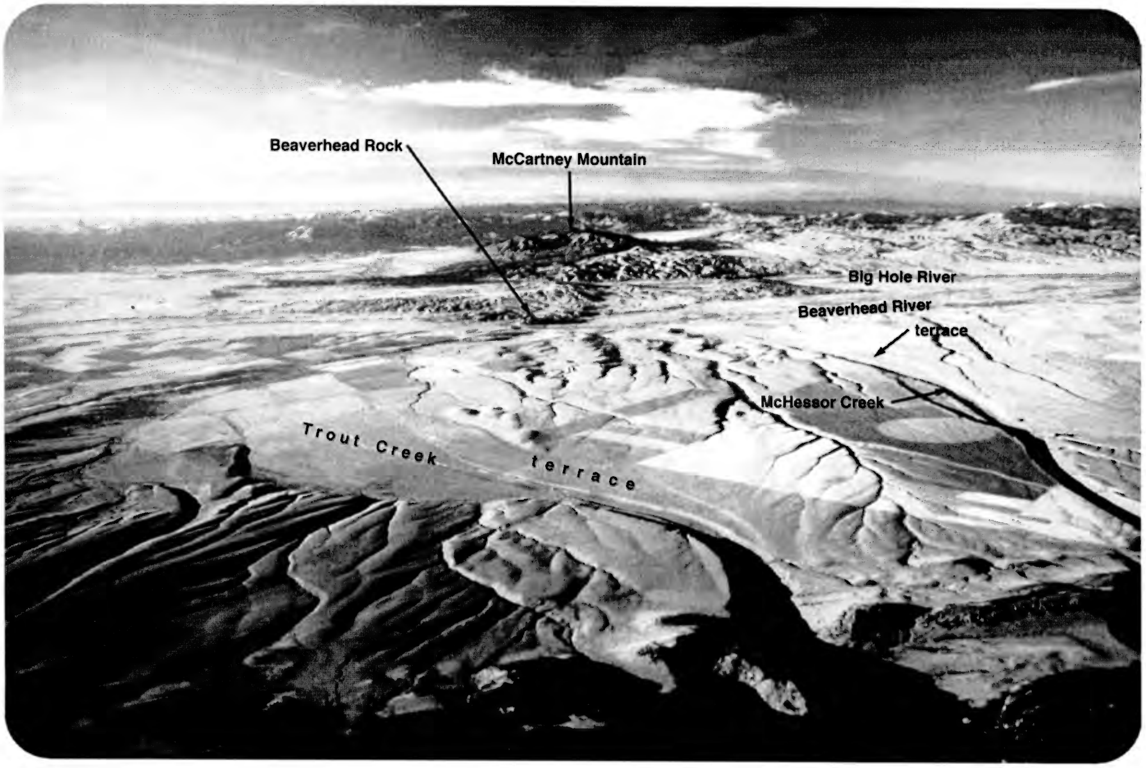


You are looking toward the south down the Boulder River along the east side of Bull Mountain. The white lines are postulated faults, a simple normal fault between the lower and upper pediment and a fault that must separate the Negro Hollow-Devil's Fence area from Bull Mountain. On the east side of the fault, Paleozoic beds dip steeply west. On Bull Mountain, Late Cretaceous Elkhorn volcanics dip steeply east. The fault would have been a younger-over-older thrust during the Laramide Orogeny and a listric (concave-upward) normal fault during the Tertiary. A significant component of the steep dip of the Elkhorn volcanics on Bull Mountain could have developed as they slid down the concave surface of the fault.

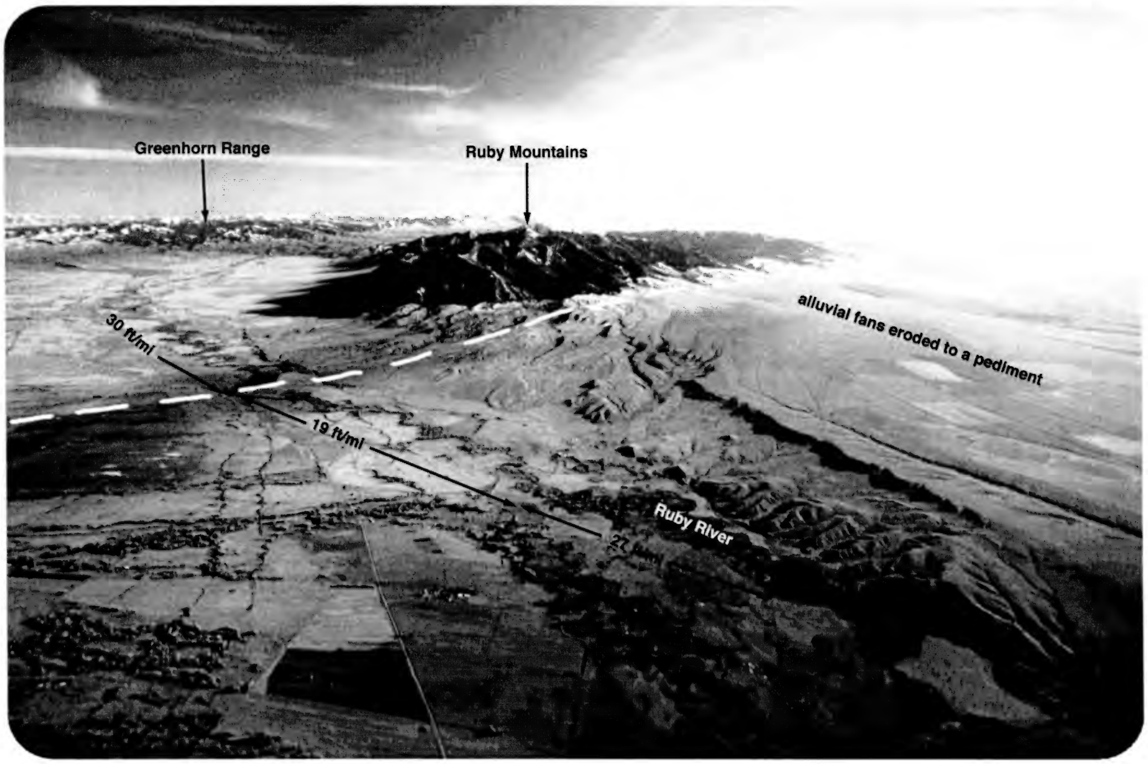
The pediments on the west side of the river are developed across Tertiary sediments. Those on the east side are developed across Paleozoic limestones and Tertiary sediments.

You are looking toward the east at McHessor Creek and Trout Creek incised across the pediment that borders the entire western flank of the Ruby Range. The terraces along these creeks merge downvalley with the modern floodplains of the two creeks. Other streams that drain the Ruby Mountains do not have terraces along them. Up arching of the northern part of the Ruby Range may have caused McHessor Creek and Trout Creek to incise below their old floodplains, leaving them as terraces. It is also possible that a catastrophic rain - flood event localized only over the northern Ruby Range caused these two creeks to cut below their former floodplains.

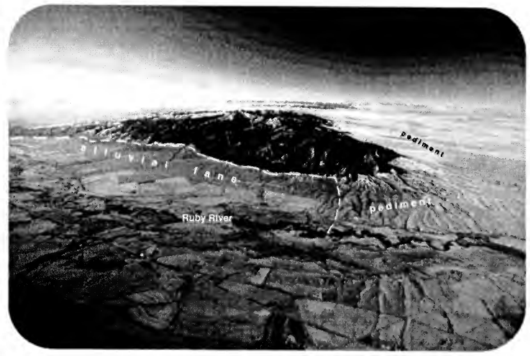




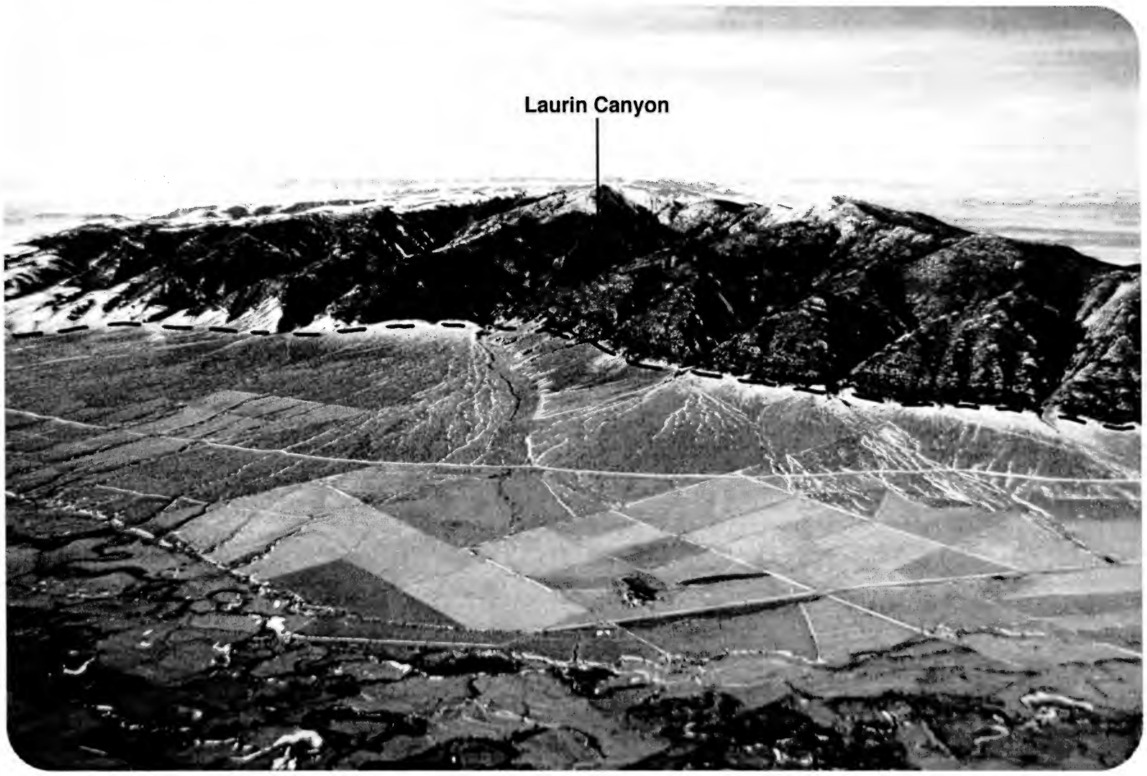
You are looking toward the northwest from over the western flank of the northern Ruby Mountains in southwestern Montana. Trout Creek and Mc Hessor Creek are the two largest creeks draining the western side of the northern Ruby Mountains. Both creeks have terraces that merge downvalley with the modern floodplains, as shown by the Trout Creek terrace in this picture.



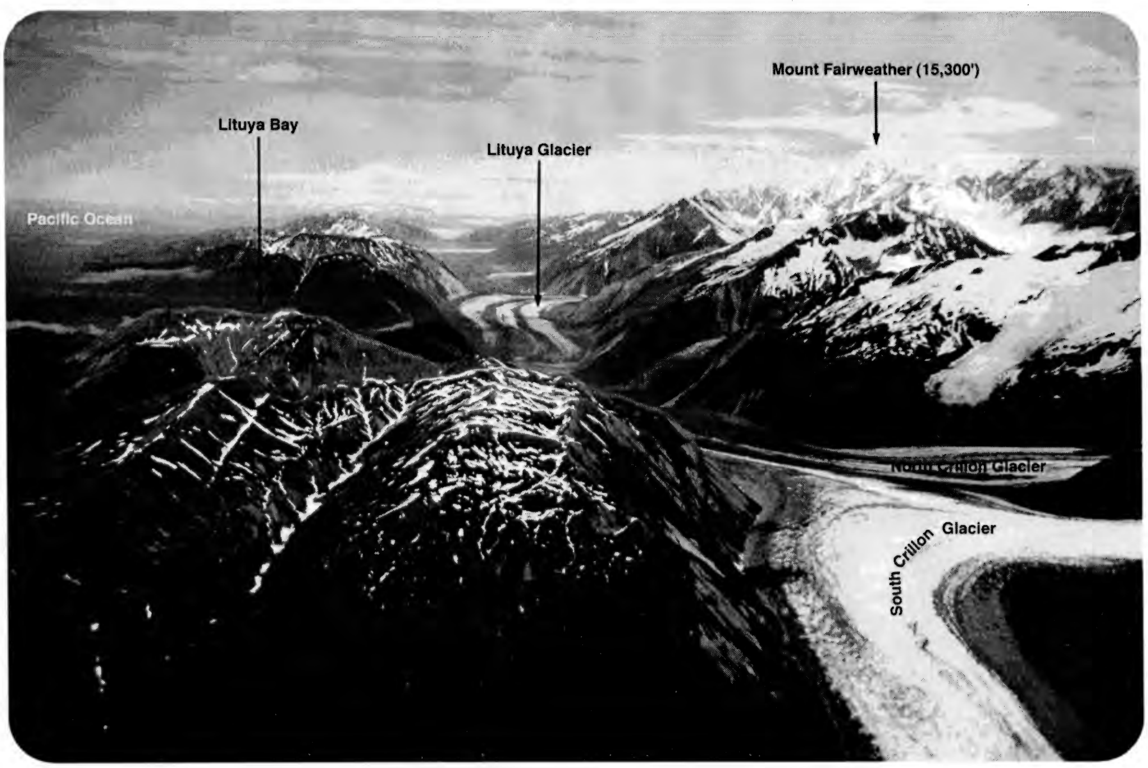
You are looking toward the southeast at the northern end of the Ruby Mountains in southwestern Montana. The Ruby River changes its pattern from tightly meandering where its valley gradient is 30 feet per mile to sinuous where its valley gradient is 19 feet per mile. It then changes back to tightly meandering where its valley gradient increases to 27 feet per mile. The white dashed line is the approximate position of the fault that borders the western side of the Ruby Mountains. The western side of the fault dropped before the pediment formed during the last interglacial episode centered about 70,000 years ago. The Ruby River eroded the scarp and filled the dropped portion with the minimum gradient (19 ft/mi) it needed to transport its load across the disrupted reach. A gravity survey conducted in 1981 by Dr. Wideman and his students located the buried fault scarp close to the white dashed line where it crosses the valley. Picture taken 1-18-81.



You are looking toward the south at the northern end of the Ruby Range in SW Montana. The block fault (dashed white line) has dropped the pediment along the northeastern flank of the Ruby Mountains. Alluvial fans have buried the pediment. The pediment on the west side of the Ruby Range wraps around the north end of the range to be truncated by the block fault on the east side. Because the last episode of pediment formation took place during the arid climate of the last interglacial interval, centered about 70,000 years ago, the movement on the block fault is more recent than that.



You are looking toward the southwest at the alluvial fans along the northeastern side of the northern Ruby Range in SW Montana. Laurin Creek and the other creeks that drain this side of the Ruby Range are incised into the fans. The incision is deepest at the heads of the fans, and the creeks merge downstream with the surfaces of the alluvial fans. These incised fans and the terraced streams on the other side of the range may indicate modern uplift of the northern Ruby Range, or they may reflect a catastrophic flood that affected only this mountain.



A SPECTACULAR FAULT

You are looking toward the northwest at a trench excavated by glaciers along the Fairweather Fault in southern Alaska. At 10:16 pm on July 9, 1958 the southwestern side of the fault lurched 35 feet upward and 21 feet to the northwest, generating an earthquake that shook loose 90 million tons of rock 3000 feet above Lituya Glacier on the northeastern side of the fault. The rockslide tore off the end of Lituya Glacier and generated a wave that rose 1740 feet on the opposite side, trimming off all trees up to that height as it swept on down Lituya Bay and out into the Pacific Ocean.* Picture taken June 26, 1989.

*Shepard, F.P. and Wanless, H.R., 1971, "Our Changing Coastlines": McGraw-Hill Book Company, p.407.