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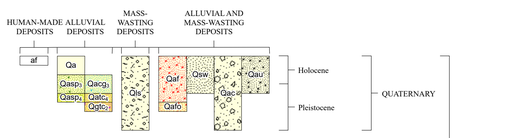
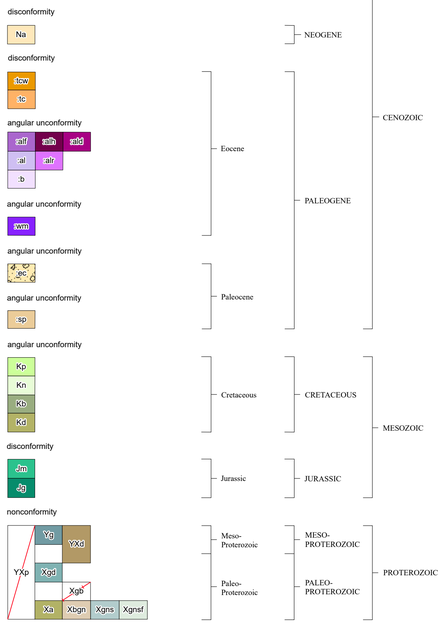
## CORRELATION OF MAP UNITS

### SURFICIAL DEPOSITS




### BEDROCK GEOLOGY

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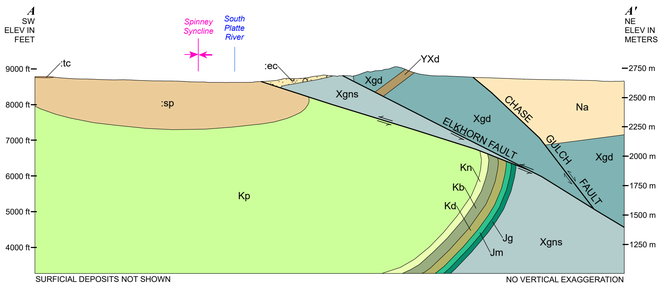


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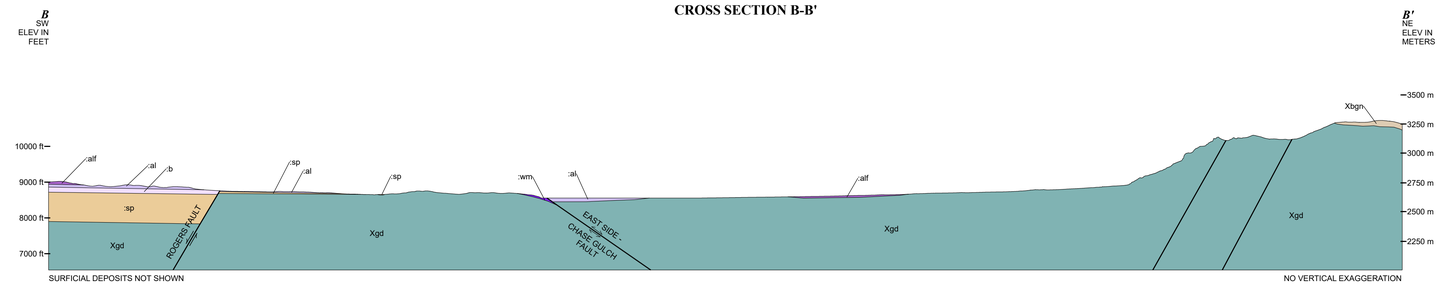


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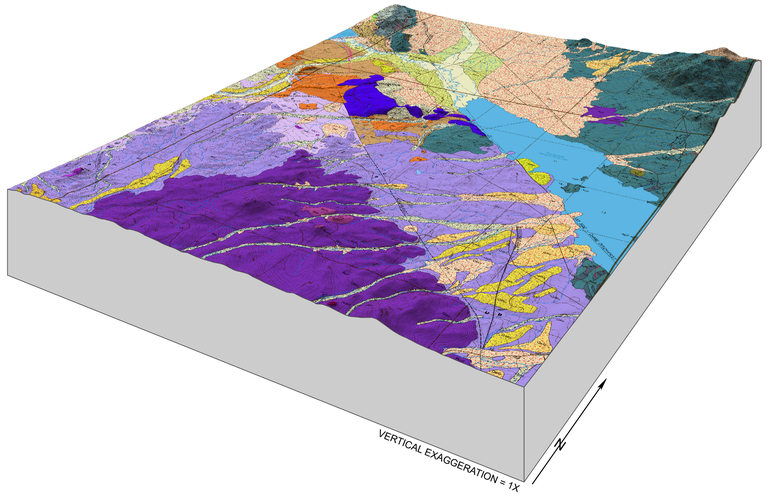
GEOLOGIC MAP OF THE SPINNEY MOUNTAIN QUADRANGLE, PARK COUNTY, COLORADO
CORRELATION OF MAP UNITS, 3-D OBLIQUE, GEOLOGIC SETTING, AND CROSS SECTIONS
By Karen J. Houck, Skyler Mavor, Kassandra O. Lindsey, and Daniel P. Miggins
2025

## 3-D OBLIQUE




## GEOLOGIC SETTING

### REGIONAL SETTING

The Spinney Mountain quadrangle is located at the southeastern end of South Park in central Colorado. It spans the Elkhorn fault system, a major structural feature that forms the western boundary of the Front Range uplift (Ruleman and others, 2011). On the eastern side of the fault, the bedrock at the land surface is mostly Proterozoic metamorphic and intrusive igneous rocks. The South Platte River runs through the quadrangle, roughly along the fault system, and is impounded for two water supply reservoirs (Spinney Mountain and Elevenmile). Numerous surficial deposits are present along the river and its tributaries. The map is also at the north end of the Eocene Thirtynine Mile volcanic field, so it contains numerous and varied volcanic rocks. Volcanic and volcaniclastic rocks form most of the bedrock at the land surface on the western (downthrown) side of the fault system.

### MAJOR STRUCTURAL FEATURES

Many periods of tectonism have affected the rock formations on this quadrangle, but those that are the most evident today are: 1) the Paleoproterozoic Colorado Orogeny, 2) the late Paleozoic ancestral Rocky Mountains Orogeny, 3) the Late Cretaceous to Eocene Laramide Orogeny, 4) Eocene-Oligocene tectonics, and 5) Neogene Rio Grande rifting. Evidence of tectonic activity during all five of these periods exists on the quadrangle, as does evidence of reactivation of several structural features. The most prominent features are as follows:

The **Hartsel uplift** underlies the quadrangle. Faulting in the uplift has divided the quadrangle into structural blocks that moved independently of each other at various times in geologic history. One set of faults is oriented at approximately N30W. It includes the Pabst-Howe, Rogers, and Elevenmile faults, and the Elkhorn fault system. The other set is oriented at approximately N65E. It includes the Gulch Road, Thunder Ridge, Wiedersphan, and Cross Creek faults.

The **Elkhorn fault system** includes the West side, Elkhorn, and East side-Chase Gulch faults, as well as associated unnamed fault strands, the Spinney syncline, and an additional unnamed syncline. It extends about 30 km north of the map area. To the south, it appears to die out (Scott and others, 1978). The down-to-the-west West side fault thrusts Cretaceous rocks over unlithified alluvium. The down-to-the-west Elkhorn fault thrusts Paleoproterozoic rocks over Cretaceous and Paleocene (?) rocks. The down-to-the-east East side-Chase Gulch fault sets Paleoproterozoic rocks against poorly lithified alluvial sediments of likely Neogene age.

The **West side thrust fault** is about 1200-1500 m long with a trace oriented at about N20W. It is an up-to-the-east fault that offsets Quaternary surficial deposits and exhibits a scarp with an average height of 1.86 m (Heerschap, 2003). Shaffer (1980) considered the possibility that the scarp could have been formed by a landslide or by gravitational spreading, but trenching confirmed that the scarp was formed by fault movement. The fault was trenched in four places (Shaffer, 1980). The average dip of the fault plane was found to be 6 to 43 degrees to the northeast. Vertical displacement of bedrock is 4 to 15 m and net displacement is 15 to 30 m. Net displacement of the surficial deposits is 2.4 m. The last fault movement is thought to have been between 13,000 and 30,000 years ago. Analysis of the scarp morphology (Heerschap, 2003) suggests that the West side fault last moved <15,000 years ago, and possibly <5000 years ago. Shaffer (1980) estimated that a surface rupture of the fault would produce a ground displacement of 5 to 10 cm.

The **Elkhorn thrust fault** is approximately 30 km long. In the map area it trends northwest. It is an up-to-the-east fault with a net displacement inferred to be about 600 to 1200 m. Its major movement is thought to have taken place during the Paleocene Epoch (Sawatsky, 1967; Shaffer, 1980; Ruleman and others, 2011). Two synclines occur on the downthrown side of the fault. The doubly plunging Spinney syncline deforms the South Park Formation. The syncline is deformed and truncated by the Gulch Road fault. A smaller, south-plunging syncline occurs in the Elkhorn conglomerate, adjacent to the Elkhorn fault. Both the South Park Formation and the Elkhorn conglomerate are thought to be Paleocene in age. The synclines formed after the deposition of these sediments. As the Tallahassee Creek Conglomerate is not folded on the west limb of the Spinney syncline, the syncline formed before the deposition of the Tallahassee Creek Conglomerate.

The **East side-Chase Gulch fault** extends about 19 km north from Spinney Mountain. In the map area it trends northwest. Rocky Mountain Energy drilled through the fault plane and found it to dip at a minimum of 50 degrees to the east. Just north of the South Platte River, it is nearly vertical (Shaffer, 1980). To the south, the fault appears to continue along the western shore of Elevenmile Reservoir. At the ground surface and at shallow depths, the fault is down-to-the-east. In NW ¼ NW ¼ sec. 12, T 13 S., R 74 W, Rocky Mountain Energy drilled through nearly 500 m of arkosic sandstone and conglomerate on the downthrown side of the fault (Shaffer, 1980). South of the Gulch Road fault, the gravity gradient across the East side-Chase Gulch fault decreases substantially (Boler and others, 1982), implying a smaller displacement south of the Gulch Road fault. Possibly some of the strain was transferred to the Rogers fault. We follow the interpretation of Shaffer (1980) that the Chase Gulch and East side faults merge at depth with the Elkhorn fault and reactivated the older thrust fault with normal-sense kinematics. We depict this relationship at depth on cross section A-A', and on cross section B-B' depict a single east-dipping fault surface that accommodated both reverse- and normal-sense displacement. Portions of the East side-Chase Gulch fault show evidence of possible Quaternary movement. Scarps are visible on the east side of Spinney Mountain. Their average height is 2.26 m (Heerschap, 2003). On the west side of Elevenmile Reservoir, Quaternary alluvium in unit Qaspg is preserved on the east side of the fault. Differential erosion was considered as a possible cause of the scarps, but was discounted when trenching and cores showed evidence of Late Pleistocene fault movement (Shaffer, 1080). The trenches showed about 9 vertical meters of down-to-the-east Quaternary movement. The last movement is thought to have been between 13,000 and 30,000 years ago. Analysis of fault scarp morphology suggests that the last movement was about 15,000 years ago (Heerschap, 2003). The maximum credible earthquake for the East side-Chase Gulch fault is estimated to be magnitude 6.2, which would cause an estimated displacement of 25 cm (Shaffer, 1980). However, these estimates assume that the East side-Chase Gulch and Elevenmile faults are connected to each other. Evidence for a connection wasn't found during this mapping project, but this may be due to poor exposure.

The **Rogers fault** is oriented parallel to the Elkhorn fault system. It is a down-to-the-west fault with at least 240 m of displacement. It offsets the Thirtynine Mile Andesite but not the Tallahassee Creek Conglomerate, indicating that its last movement was in the Eocene Epoch.

The **Elevenmile fault** is a splay of the Rogers fault. It is 4.8 km long and trends N14W. It is a down-to-the-east fault. A scarp can be seen along the fault that displaces units Qatc$_4$ and Qaf by about 1.8 m. Groundwater ponds west of the fault trace in the valleys of Union and Gilead creeks. The scarp is similar to those of the East side and West side faults, so it is inferred that the last movement also took place 13,000 to 30,000 years ago (Shaffer, 1980). Analysis of the fault scarp morphology showed that the average scarp height is 1.41 m and suggests that the last movement on the fault was >15,000 years ago (Heerschap, 2003). The maximum credible earthquake on the fault is one of magnitude 6.2, and this is predicted to result in a displacement of 25 cm (Shaffer, 1980). As was noted in discussion of the East side-Chase Gulch fault, this is based on the assumption that the Elevenmile fault is connected to the East side-Chase Gulch fault.

The **Pabst-Howe fault** is also a northwest-trending, down-to-the-west fault that parallels the Elkhorn fault system. On the adjoining Guffey NW quadrangle, approximately 2500 m of displacement (Durrani, 1980) is associated with a prominent gravity gradient (Boler and others, 1982). To the south, it either dies out or is concealed under the Thirtynine Mile Andesite.

The **Gulch Road fault** is the northernmost in a series of four faults oriented at about N50E to N70E. It extends for a distance of at least 12 km from the Currant Creek fault on the Guffey NW quadrangle to the Elkhorn fault system on the Spinney Mountain quadrangle. It coincides with the southern edges of gravity lows on both the Guffey NW and Spinney Mountain quadrangles (Boler and others, 1982). The Spinney syncline is truncated abruptly at the fault, as is a large syncline on the Guffey NW quadrangle. The earliest and largest movement was down-to-the-north. It occurred after the deposition of the South Park Formation, but before the deposition of the Thirtynine Mile Andesite. A later, down-to-the-south movement occurred to deform the Tallahassee Creek Conglomerate. The Gulch Road fault is a major structure that appears to have compartmentalized strain in the rocks north and south of it.

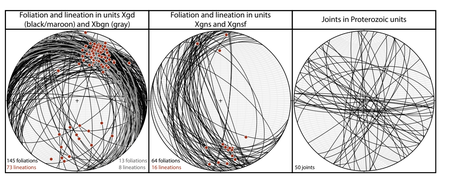
The **Thunder Ridge fault** is a northeast-trending, questionable fault that may crosscut the Wall Mountain Tuff and continue below the Tallahassee Creek Conglomerate. Its sense of motion is unknown.

The **Wiedersphan fault** is a northeast-trending, down-to-the-south fault that is marked by a line of hydrothermal alteration along the fault trace. It does not appear to crosscut the Tallahassee Creek Conglomerate. Exposure of the Balfour Formation is not adequate to determine whether the fault crosscuts it. The fact that the lower member of the Thirtynine Mile Andesite is preserved only south of it suggests that the last episode of fault movement may have occurred after deposition of the Thirtynine Mile Andesite, but before deposition of the Tallahassee Creek Conglomerate.

The **Cross Creek fault** is a northeast-trending fault that may have experienced an episode of down-to-the-north movement prior to the deposition of the Wall Mountain Tuff. Alternatively, the tuff on the south side of the fault may have been deposited on an erosional remnant of unit Xgd. After the tuff was deposited, the fault experienced down-to-the-south movement that deformed the tuff on the north side of the fault. Presumably, this occurred before the deposition of the Tallahassee Creek Conglomerate because the conglomerate was not deformed or offset by the fault.

### STRATIGRAPHY AND STRUCTURAL EVOLUTION

The oldest units in the quadrangle are high-grade Proterozoic gneisses, amphibolite, and granodiorite (units Xbgn, Xgns, and Xa) exposed in the hanging wall of the Elkhorn thrust. A sample collected from unit Xgnsf (sample number SM586) yielded a $^{207}Pb/^{206}Pb$ zircon age of 1708.7±6.6 Ma. At least three deformation events are recorded by fabrics in unit Xgns; isoclinal folds demonstrate transposition of an early fabric to parallelism with the dominant gneissic foliation that dips steeply to shallowly WSW. This foliation is gently folded around a shallowly NNW-plunging axis. These oldest units are intruded by an extensive porphyritic granodioritic gneiss (unit Xgd). A sample collected from this unit yielded a $^{207}Pb/^{206}Pb$ zircon age of 1712.9±6.4 Ma. Foliation within unit Xgd is largely N- or NE-dipping with a down-dip lineation. This foliation parallels the foliation within unit Xgns near where unit Xgd intrudes unit Xgns. Foliation in units Xa and Xbgn largely parallels that within unit Xgd. Unit Yg, which intrudes unit Xgd, generally lacks foliation and either intrudes parallel to or cuts oblique to the foliation in unit Xgd. However, sparse observations of a weak foliation defined by aligned biotite grains within unit Yg that parallels the unit Xgd foliation could suggest late synkinematic intrusion. NW- and NNW- striking brittle faults, one with apparent SE-down separation, cut the Proterozoic units exposed on the slopes of Stoll Mountain, though the timing of this faulting is unclear. Jointing in Proterozoic rocks is dominated by subvertical planes ranging from WNW to NNE striking, though other joint orientations are also observed. As groundwater movement in the Proterozoic rocks occurs in joints, the joint orientations are helpful in understanding how movement will occur in areas underlain by these rocks.




The widespread distribution of lower and middle Paleozoic sedimentary rocks in central Colorado (Ross and Tweto, 1980) suggests that these rocks were originally deposited on the Spinney Mountain quadrangle but were later eroded. During the late Paleozoic Era, the quadrangle was part of the Frontrangia uplift (Mallory, 1958). If upper Paleozoic sediments were ever deposited in this area, they too were subsequently eroded, likely along with the remaining lower and middle Paleozoic rocks.

The Mesozoic Era is thought to have been a time of local tectonic quiescence. In the map area, the Garo (Jg) and Morrison (Jm) formations were deposited during the Jurassic Period, in continental environments. As the Western Interior Seaway encroached on the area, the Dakota Sandstone (Kd), Benton Group (Kb), Niobrara Formation (Kn), and Pierre Shale (Kp) were deposited in marginal marine and marine environments.

The Laramide Orogeny began in the latest Mesozoic to earliest Cenozoic era, when the Jurassic and Cretaceous rocks were folded and faulted. Subsequently, during the Paleocene Epoch, the debris flows and alluvium of the South Park Formation (Ptsp) and Elkhorn conglomerate (Ptec) were deposited with angular unconformity on the Cretaceous rocks. After deposition, these formations were also folded and faulted. The Elkhorn fault system, the Rogers fault, and the Pabst-Howe fault appear to have been active at this time, with down-to-the-west movement. The Gulch Road and Cross Creek faults were also active, with down-to-the-north movement.

The next-oldest rock formation preserved on the quadrangle is the Wall Mountain Tuff (Ptwm), which was emplaced in the Eocene Epoch as a massive pyroclastic flow. It is preserved at the surface only on the fault block bounded by the Rogers, Gulch Road, and East side/Chase Gulch faults.

Following deposition of the Wall Mountain Tuff, the Thirtynine Mile volcanic series was emplaced in the late Eocene Epoch. The oldest formation in the series (the Balfour Formation; Ptb) was deposited as volcaniclastic alluvial, debris flow, and lacustrine sediments. This was followed by emplacement of the volcanic breccias and lava flows of the lower member of the Thirtynine Mile Andesite. The lower part of the lower member (Ptal) is mostly volcanic breccias with minor unbrecciated flows that issued from a great number of small vents in the map area. The upper part of the lower member (Ptalf) has noticeably more and thicker unbrecciated flows. Though most of the lower member is pyroxene andesite porphyry, small areas of rhyodacite porphyry (Ptalr), hornblende andesite porphyry (Ptalh), and a diorite plug (Ptald) were also found.

In the latest Eocene Epoch, the Tallahassee Creek Conglomerate (Pttc) was deposited as debris flows and alluvial sediments in paleovalleys that formed after the deposition of the Thirtynine Mile volcanic series. Late in Tallahassee Creek time, a facies consisting almost entirely of Wall Mountain Tuff boulders (Ptctcw) was deposited in proximity to the Wall Mountain Tuff outcrops.

Though the main pulse of the Laramide Orogeny in this area appears to have been in Paleocene time, a high level of tectonic activity continued throughout the Eocene Epoch. The Wall Mountain Tuff, Thirtynine Mile volcanic series, and Tallahassee Creek Conglomerate are separated from each other by angular unconformities. The north-northwest trending Rogers fault shows evidence of down-to-the-west Eocene movement, which is the same sense of motion that the north-northwest trending faults (Rogers, Pabst-Howe, and Elkhorn system) had during the Paleocene phase of the Laramide Orogeny. However, the northeast-trending Gulch Road, Wiedersphan, and Cross Creek faults show evidence of down-to-the-south Eocene motion. This is the opposite of the sense of motion that occurred on the Gulch Road and Cross Creek faults during the Paleocene phase of the orogeny. These relationships suggest that the Eocene tectonic activity in the map area did not result solely from the continuation of the Laramide stress field. Rather, there was a change in the Eocene stress field that caused movement reversals on the northeast-trending faults. Given the large amount of magmatic activity that occurred beneath the map area during the formation of the Thirtynine Mile Andesite, magma movements could have been one possible contributing factor to the change in the stress field.

The only possible Oligocene, Miocene, or Pliocene rocks preserved in the map area are on the downthrown side of the East side-Chase Gulch fault. Their preservation likely resulted from down-to-the-east, late Paleogene to Neogene movements on these faults. This normal fault movement may have been related to the opening of the Rio Grande Rift (Shaffer, 1980). The next available information about the geologic history of the quadrangle comes from Quaternary surficial deposits and possible fault scarps. Inset alluvial terraces remain as evidence of active fluvial systems during the Holocene and Pleistocene. The inset relationship of the terraces indicates a repetitive cycle of deposition and incision by the ancestral South Platte River and its tributaries, leaving older, isolated, gravel-capped surfaces at higher elevations in the landscape. The oldest gravel deposited by ancestral stream systems in the mapped area is unit Qgtc$_2$ (Middle Pleistocene).

During the Late Pleistocene and Early Holocene, glacial-ice covered higher elevations west of the mapped area. When the Bull Lake and Pinedale glaciations culminated, there was significant water in the drainage networks adjacent to and within the mapped area. Four units record periods of deposition in gravelly alluvium mapped as units Qatc$_4$, Qaspi$_4$, Qaspi$_3$, and Qacg$_3$. Units Qatc$_4$ and Qaspi$_4$ are roughly correlative with the end of the Bull Lake Glaciation which culminated around 120 ka in the Arkansas River valley (Schweinsberg and others, 2020). Lower terraces underlain by units Qaspi$_3$ and Qacg$_3$ are roughly correlative with the end of the Pinedale Glaciation, which culminated around 14 to 15 ka (Young and others, 2011; Schweinsberg and others, 2020). During the Middle and Late Holocene, modern drainages deposited unit Qa on low-lying terraces and floodplains adjacent to the South Platte River, Threemile Creek, and Chase Gulch.

Throughout the Early Pleistocene and Holocene, rainstorm events deposited units Qaf, Qafo, Qau, and Qsw in the mapped area. Unit Qafo southwest of Eleven Mile Reservoir was likely deposited predominantly during the Late Pleistocene. The unit underlies fan-shaped surfaces that are topographically lower than unit Qatc$_4$, which is interpreted as correlative with the end of the Bull Lake Glaciation. Deposits in the northeast corner are fairly thin, approximately 1.5 m thick. Given how thin the deposits are and their higher relative elevations to nearby drainages compared to deposits southwest of Eleven Mile Reservoir, the unit mapped in the northeast corner is likely older than in the south. It is at least as old as pre-Bull Lake (Middle Pleistocene) and may be as old as Eocene in age (Epis and others, 1979). Unit Qaf is topographically lower than unit Qafo but likely deposited in very similar ways during the Holocene. If the scarps on the West side, Chase Gulch, East side, and Elevenmile faults were formed by fault movement, then that movement occurred after deposition of unit Qaf. Inferred Quaternary movement on the West side fault was down-to-the-west (reverse movement), whereas inferred Quaternary movement on the Chase Gulch, East side, and Elevenmile faults was down-to-the-east (normal movement). This movement may have resulted from continued activity in the Rio Grande Rift (Shaffer, 1980). Wall Mountain Tuff clasts are deposited as unit Qac in an apron-shaped landform below an outcrop near the northwest tip of Eleven Mile Reservoir. Clasts rolled or fell away from the outcrop sporadically during the Pleistocene and Holocene. Landslides initiated near contacts with or within relatively weak bedrock units and have deposited unit Qls during the Pleistocene and Holocene.

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