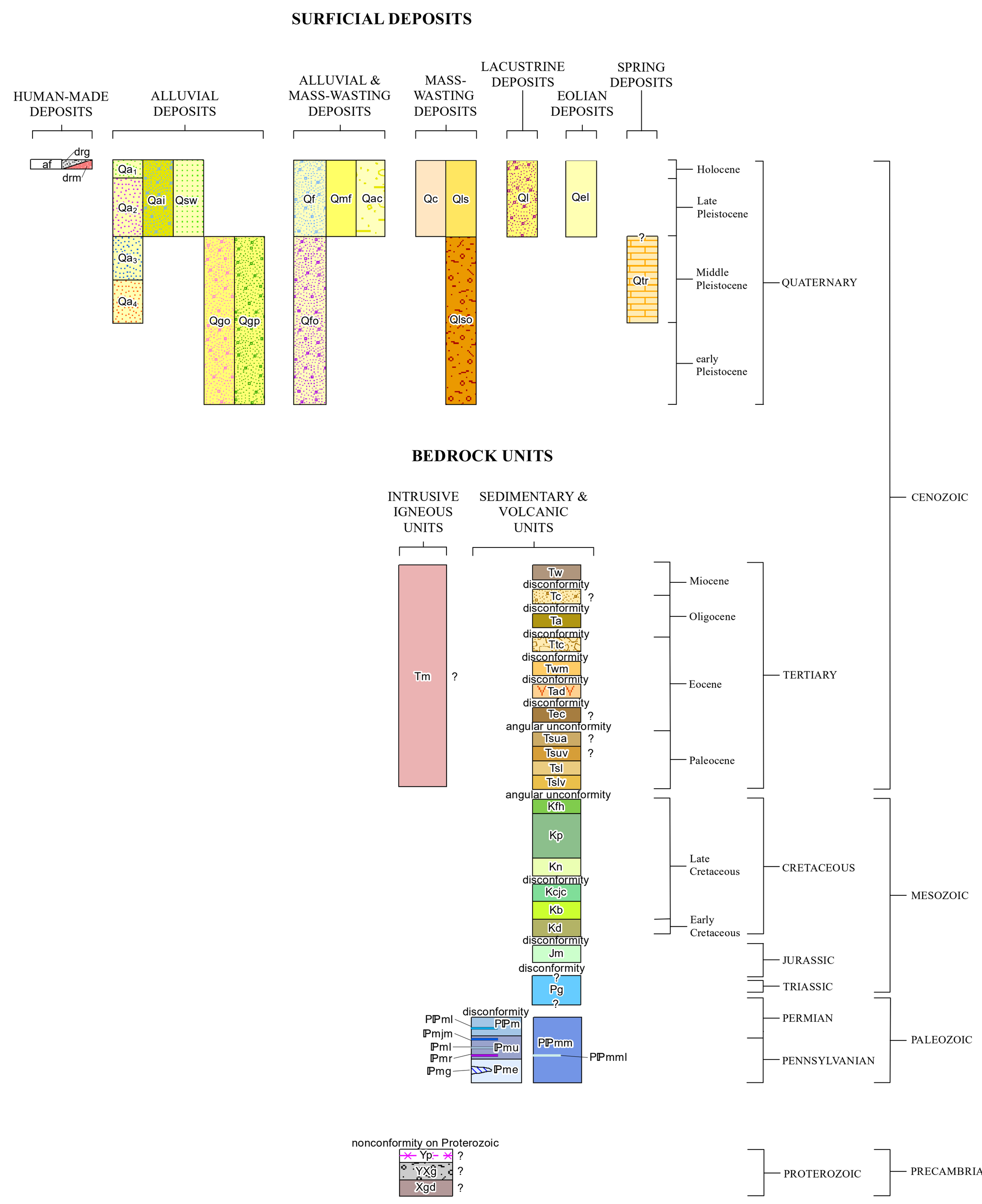
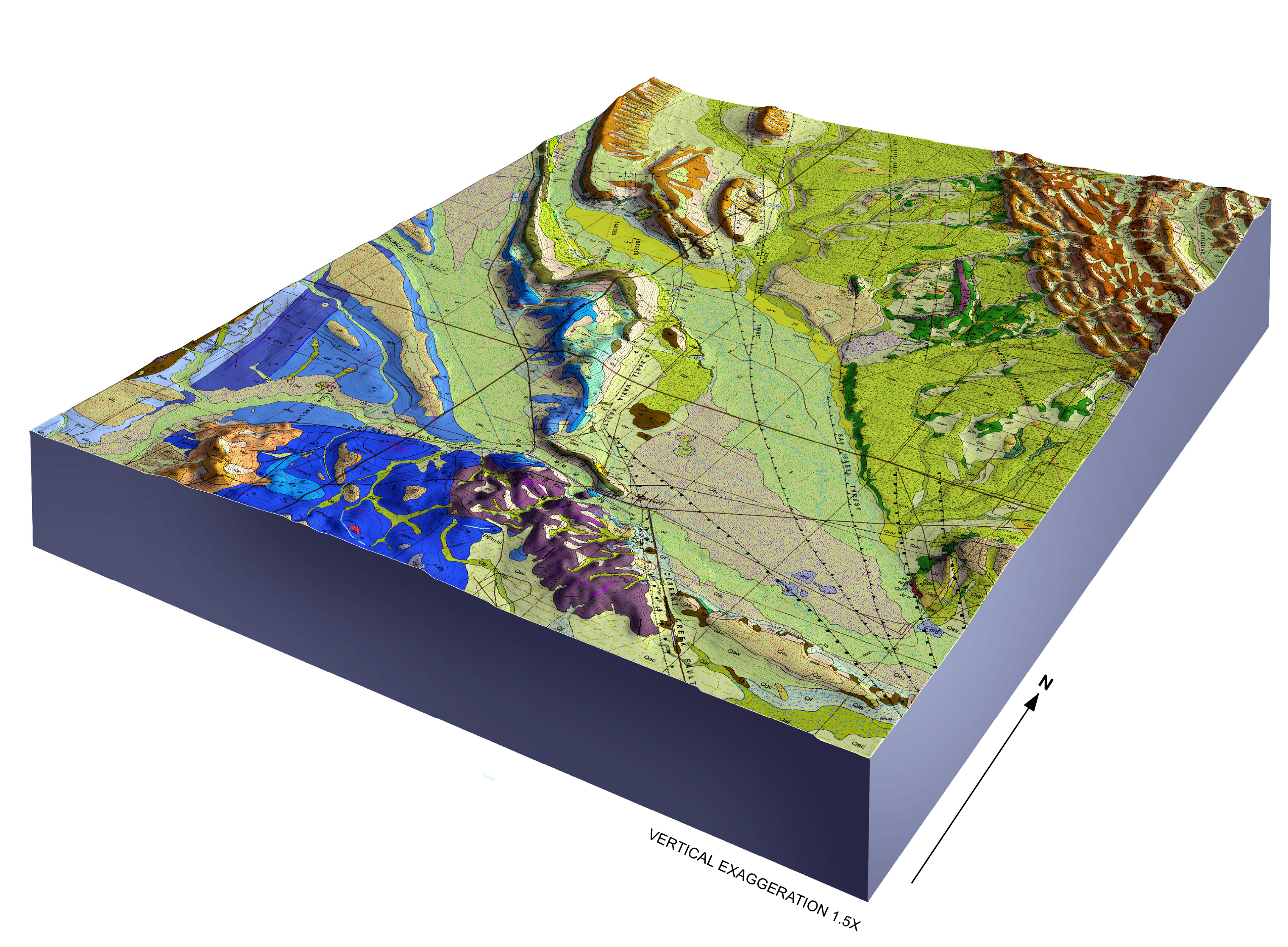
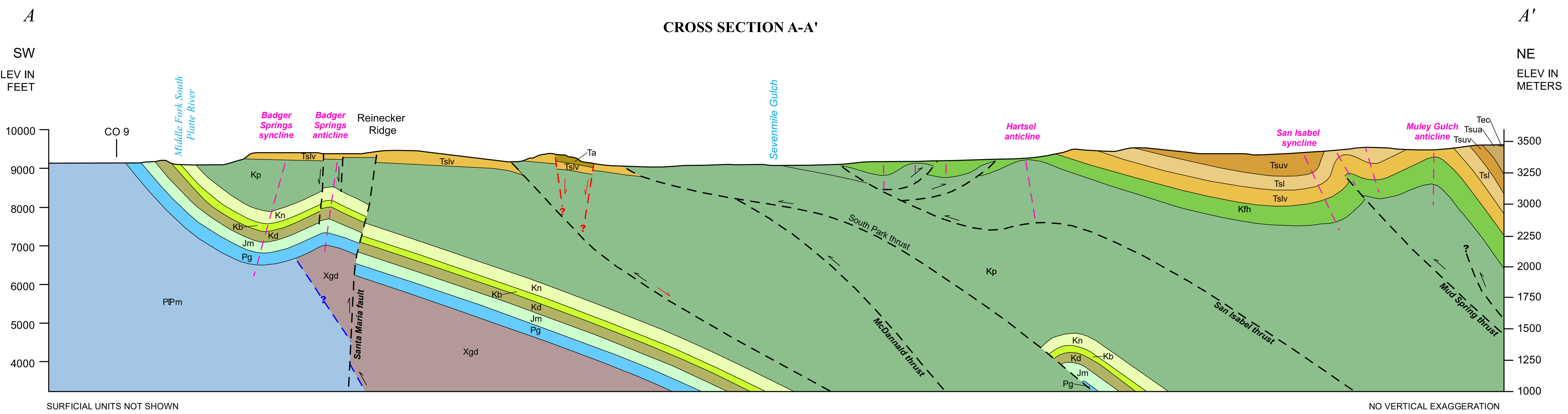
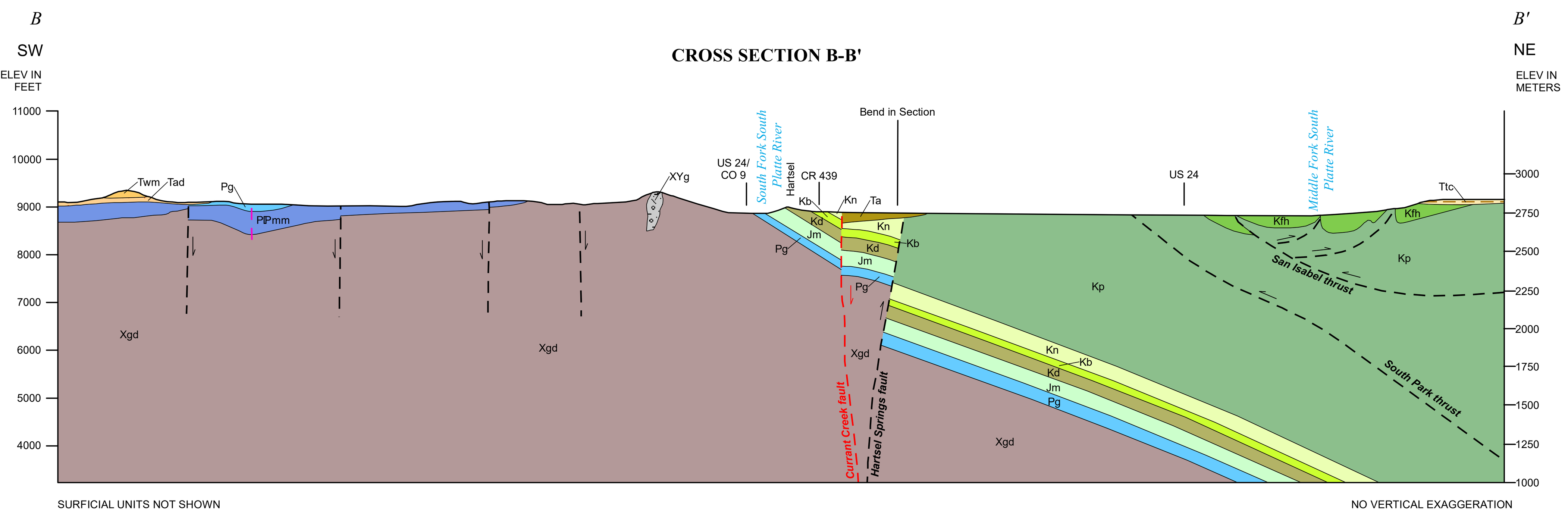
CORRELATION OF MAP UNITS[1]



3-D OBLIQUE VIEW OF GEOLOGIC MAP







FAULT SYMBOLOGY

- Interpreted fault boundary between the Pennsylvanian/Permian Frontrangia uplift and central Colorado trough
- Faults active during Laramide deformation arrow shows displacement
- Faults active during Neogene or younger arrow shows displacement
- Fold axis

Note: Interpretation of subsurface fault geometry east of the Santa Maria and Hartsel Springs faults in the cross sections is based on seismic and deep borehole data (Clement and Dolton, 1970; N. Sterne, written communication, 2016).

GEOLOGIC MAP OF THE HARTSEL QUADRANGLE, PARK COUNTY, COLORADO
CORRELATION OF MAP UNITS, 3-D MAP, CROSS SECTIONS, AND GEOLOGIC SETTING

By Peter E. Barkmann, Karen J. Houck, Marieke Dechesne, Jonathan R. Lovekin, and Erinn P. Johnson
2017

GEOLOGIC SETTING

Regional Setting

The Hartsel quadrangle sits nearly in the center of the complex South Park Laramide structural basin. Generally, the basin can be described as an asymmetrical down-faulted feature, dipping to the east. It is bounded by two northwest-trending uplifts: the Sawatch uplift to the west and the Front Range uplift to the east. The west-verging Elkhorn thrust, which places Proterozoic intrusive and metamorphic rocks within the Front Range uplift over Phanerozoic sediments in the basin, passes just east of the quadrangle. Seismic data and deep oil and gas well logs indicate that a series of imbricate thrust faults extend west, and in front of, the Elkhorn thrust fault. The Hartsel uplift is a westward-jutting structural salient of the Front Range uplift that brings Proterozoic rocks farther into the basin south of the town of Hartsel. The quadrangle also spans the late Paleozoic boundary between the central Colorado trough (DeVoto, 1972) to the west and Frontrangia (Mallory, 1958) to the east. The Neogene Rio Grande rift system lies to the west of South Park Basin in the upper Arkansas River valley. Examples of Neogene extension can be found throughout South Park, as described by Stark and others (1949), De Voto (1971), and Ruleman and others (2011). In addition, there is evidence of ongoing local deformation related to dissolution and possible collapse of Paleozoic evaporite deposits across much of the west side of the basin (Kirkham and others, 2012).

Stratigraphy

Precambrian crystalline igneous rocks are exposed at the surface within the Hartsel uplift in the southern part of the quadrangle. The dominant unit is a granodiorite pluton (Xgd) that is intruded by younger small granitic stocks (YXg) and numerous pegmatite bodies (Yp). Locally, the granodiorite appears hydrothermally altered, as well as deeply weathered.

No lower or middle Paleozoic rocks are exposed within the quadrangle; the nearest exposures are on Trout Creek Pass, approximately 10 miles (16 km) to the southwest. However, these rocks may be present in the subsurface in parts of the quadrangle. In the late Paleozoic Era, mountain ranges and marine basins developed in the western United States. In central Colorado, a mountain range known as Frontrangia (Mallory, 1958) extended across the state and was oriented north-northwest to south-southeast. It was flanked on the west by a marine basin, the central Colorado trough (DeVoto, 1980). Coarse, arkosic sediments were eroded from Frontrangia and deposited in the central Colorado trough. In the Hartsel quadrangle, these sediments became the Minturn and Maroon Formations. The late Paleozoic Era was a time of frequent sea level changes caused by waxing and waning of glaciers in the southern hemisphere (Rygel and others, 2008), so the Minturn and Maroon Formations contain a wide variety of marine and nonmarine deposits.

The Hartsel quadrangle straddles the boundary between Frontrangia and the central Colorado trough. North of the Hartsel fault, the boundary is concealed by younger sedimentary rocks; it is thought to be a fault boundary at the approximate position of Reinecker Ridge (Nesse, 2006; N. Sterne, written communication, 2016). An inferred configuration of the boundary is shown in cross section A-A'. Over 6,300 feet (1,935 m) of Middle Pennsylvanian to Permian (?) sedimentary rocks are exposed at the surface. These include marine evaporites in unit ℙme, as well as arkosic conglomerate, sandstone, siltstone, shale, and marine limestone in the upper Minturn and Maroon Formations (ℙmu and Pℙm). Above the Robinson Limestone Member of the Minturn Formation (ℙmr), the arkosic sediments become much coarser. Paleocurrents in the fluviodeltaic sandstones and conglomerates are directed northward, and clast sizes decrease in a northward direction.

At the Hartsel fault, the boundary between Frontrangia and the central Colorado trough jogs to the west. South of the fault, approximately 200 feet of undifferentiated upper Minturn and Maroon Formations (Pℙmm) overlie a deep weathering zone on the top of the Proterozoic igneous rocks, with no intervening lower to upper Paleozoic rocks. In addition to Proterozoic igneous rocks, conglomerate clasts include Maroon-like shale, siltstone, sandstone, and limestone, implying that erosion and redeposition occurred. Though smaller, the lens-shaped marine limestone bodies are similar to the bioherms documented in the Minturn Formation on the east edge of the central Colorado trough in the Minturn area (Walker, 1972).

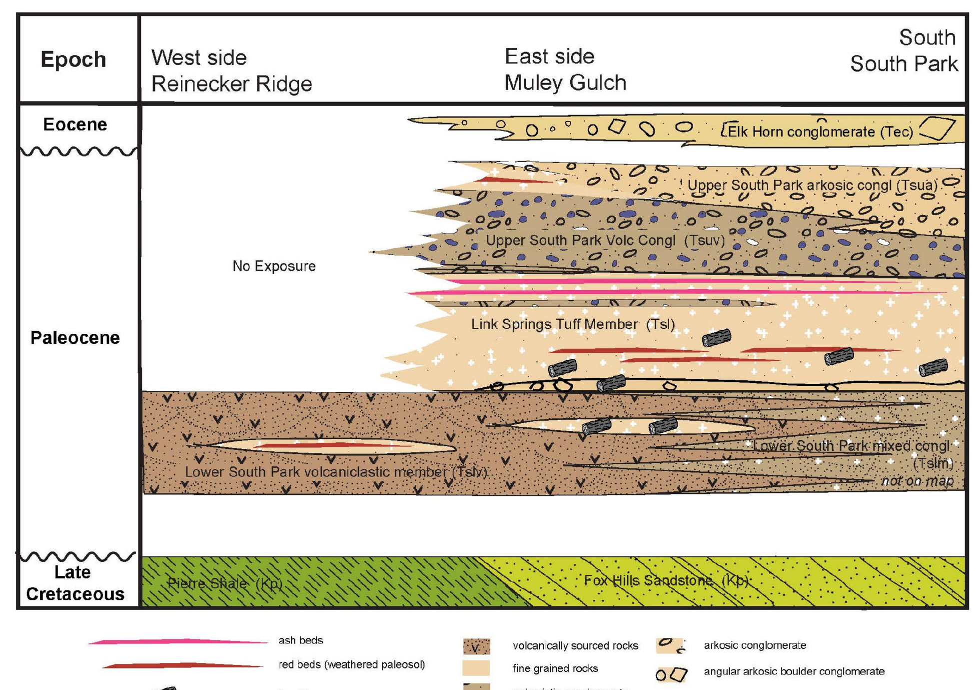
Taken together, the features described above indicate that the area south of the Hartsel fault was uplifted in the late Paleozoic Era as part of Frontrangia (DeVoto, 1971), and that it supplied sediment to the central Colorado trough on the Hartsel quadrangle. The features also indicate that the Hartsel fault was active in the late Paleozoic Era, and that it formed the boundary between the central Colorado trough to the northwest and Frontrangia to the southeast. The Robinson Limestone Member has been dated as Middle Pennsylvanian (middle Desmoinesian; Tillman, 1971), so the flood of coarse, arkosic sediments preserved in the upper Minturn and Maroon Formations was deposited in response to movement on the Hartsel fault, during and/or after the middle Desmoinesian Age.

Following uplift of Frontrangia, the region was subaerially exposed and subject to erosion combined with minor sediment deposition from Permian (?) through Jurassic Periods. Strata from this period consist of the Garo Sandstone (Pg) and the Morrison Formation (Jm). Historically, the Garo Sandstone was considered to be Jurassic in age (Singewald, 1942; Stark and others, 1949) and possibly correlative with the Entrada Sandstone found farther to the west in the Colorado Plateau region (Scarbrough, 2001). DeVoto (1965) argued that the Garo Sandstone is conformable upon, and may even interfinger with, the underlying Maroon Formation, and therefore is Permian. Colorado Geological Survey geologists have adopted the Permian assignment of DeVoto (1965). Assignment of the Garo Sandstone to the Permian or Jurassic continues to be uncertain and poses a critical question about timing of the beveling of the Frontrangia landscape. Regionally, it is found directly above both Precambrian crystalline rocks of Frontrangia to the east and the central Colorado trough sediments to the west. Within the map area, the Garo Sandstone overlies the Maroon Formation north and west of the Hartsel uplift and directly above Precambrian granodiorite on the east side of the Hartsel uplift.

Marine sediments blanketed the entire Rocky Mountain region between approximately 110 and 70 million years ago (Ma) marking the encroachment and eventual retreat of the Western Interior Seaway (Cobban and others, 2006). Sedimentary units deposited during this marine incursion cross the central part of the quadrangle in a broad northwest-trending belt and include the Dakota Sandstone (Kd), Benton Group (Kb), Niobrara Formation (Kn), Pierre Shale (Kp), and Fox Hills Sandstone (Kf). These units are genetically linked by their direct association with the interior seaway, representing marine, shoreline or coastal plain environments. With the exception of the Dakota Sandstone, most of the units are poorly exposed.

The Laramide orogeny began in the Late Cretaceous and continued into the Eocene (Tweto, 1980) as a period dominated by compressional deformation. The South Park Formation represents the synorogenic sediments deposited in the South Park Basin during the Laramide orogeny and rests on an angular unconformity above the underlying deformed Upper Cretaceous sediments. It has been subdivided into formal and informal members based on compositional differences reflecting changes in source areas and depositional environments (Sawatzky, 1967; Wyant and Barker, 1976; Widmann and others, 2005; Kirkham and others, 2006; Ruleman and Bohannon, 2008; Ruleman and others, 2011). Stratigraphic relationships of the various members are complex and member assignments from other locations within South Park do not strictly carry into this quadrangle. The block diagram below illustrates the relationships of the units identified in this quadrangle and members include, in ascending order: a lower volcaniclastic member (Tslv), the Link Spring Tuff Member (Tsl), an upper volcaniclastic member (Tsuv) and an upper arkosic conglomeratic member (Tsua). The upper two have not been described as such in nearby quadrangles, yet form distinct mappable units in this area. These units are given new informal names herein. An upper conglomerate, described as a syn-tectonic unit by Ruleman and Bohannon (2008) and Bohannon and Ruleman (2009) rests on an angular unconformity above deformed South Park Formation. This unit, called the syn-tectonic conglomerate by Ruleman and others (2011) and herein given the informal name of Elkhorn conglomerate (Tec), appears to have been deposited during and/or after deformation by the Elkhorn thrust.

Stratigraphic Relationships of South Park Formation Units in Hartsel Area



Tectonism continued after the Laramide orogeny but was characterized by extension combined with erosion. Rock units in South Park record continued volcanism accompanied by fluvial and lacustrine sedimentation. A prolonged period of broad erosion led to beveling of the landscape following the Laramide tectonic event. Post-Laramide volcanism in the area began in the Eocene with centers to the west and continued through approximately 33 Ma with centers to the south. Volcanic rocks within this map area include andesitic flows and volcaniclastic units (Tad) similar to those mapped in the Lone Hills in the Garo quadrangle just to the west (Kirkham and others, 2007) and the Wall Mountain Tuff (Twm).

Sediments accumulated in the region contemporaneously with active volcanism in the Eocene, Oligocene, and Miocene Epochs. Stratigraphic relations between sediments and volcanic rocks are complex and continue to be refined through ongoing mapping efforts. The Eocene Tallahassee Creek Conglomerate (Ttc) and Oligocene Antero Formation (Ta) are interbedded with the volcanic flows and tuffs while the Miocene Wagontongue Formation (Tw) was deposited later, after quiescence of the Oligocene volcanic event.

Quaternary deposits include alluvium (Qa_4, Qa_3, and Qa_2) and post-glacial alluvium along modern streams (Qa_1). Tributary drainages, many of which are ephemeral (Qai), emerge into lowlands to form fans. Where watersheds are dominated by resistant bedrock, the fans are made up of coarse grained alluvium with steep slopes (Qf); and where the watersheds are dominated by less resistant bedrock, the fans are made up of fine grained sediment (Qmf) with very low slopes. Much of the region is blanketed with colluvium and sheetwash deposits (Qc and Qsw) with older deposits mantling strath pediment surfaces over exposed bedrock above modern streams (Qgp). Locally, older gravel deposits from abandoned channels (Qgo) form inverted topography as ridges or flatirons. Landslides (Qls) are common, particularly where the bedrock is shale. Numerous natural depressions that are either eolian wind-scour features or evaporitic karst above Pennsylvanian evaporite beds are filled with lacustrine playa deposits (Ql).

Structural Features

Three periods of tectonism have imparted a structural fabric on this quadrangle: (1) the late Paleozoic ancestral Rocky Mountains orogeny, (2) the Late Cretaceous to Eocene Laramide orogeny, and (3) post-Laramide extensional tectonics. Structural elements with histories of deformation are present from each and evidence exists of reactivation of several features. Deformation during these periods occurred along the following primary features:

Hartsel uplift is the area south and west of the town of Hartsel where Precambrian crystalline bedrock is exposed at the surface and appears to be a Laramide feature. Stratigraphic relationships in the Minturn and Maroon Formations suggest that it was also part of the late Paleozoic Frontrangia highland.

Hartsel fault trends northeasterly for approximately 4 miles (6.4 km) in the southwest part of the quadrangle where it bounds the northwest side of the Hartsel uplift. It appears to have been active during the late Paleozoic as well as the Laramide since it displaces Late Cretaceous sediments along the hogback north of the intersection of US Highway 24 and State Highway 9. Sense of movement on the Hartsel fault appears complex with stratigraphic evidence in the Maroon Formation for down-to-the-north displacement along a fault in this area. Subsequent movement has apparent displacement of down-to-the-south. It may be a compartment fault and there is the possibility of strike-slip movement.

Hartsel Springs fault is an inferred fault that trends west-northwesterly for approximately 4 miles (6.4 km) in the southeast part of the quadrangle where it bounds the northeast side of the Hartsel uplift. This fault is informally named herein and is inferred based on exposures of Niobrara Formation and the Juana Lopez Member of the Carlile Shale less than 1 mile (1.6 km) southeast of the town of Hartsel between the Currant Creek fault and the South Fork South Platte River. Exposures of these formations, which are found below the Pierre Shale, in this location require a fault with displacement of approximately 1,000 ft (305 m), down-to-the-north, beneath the Quaternary valley fill. Much younger Pierre Shale and Fox Hills Sandstone are exposed just to the north. It has Laramide deformation with northeast side down of approximately 1,400 ft (427 m) displacement. It is inferred to be a reverse fault that underlies the inclined Mesozoic strata heading northwest from Hartsel.

Arrowhead Ranch fault is a major west- to northwest-trending compartment fault that extends over 11 miles (18 km) to the west across the Garo and Jones Hill quadrangles into the Mosquito Range (Kirkham and others, 2007; Widmann and others, 2011). Displacement in the Garo quadrangle just to the west, is south side down with approximately 1,000 ft (305 m) of stratigraphic displacement. Displacement varies along its trace and on this quadrangle the north side is down.

Badger Springs folds are a set of anticlines and synclines that deform the hogback of Mesozoic strata that heads northwest from the town of Hartsel. The axes plunge north and then swing to the northwest. The amplitude of the main anticline is approximately 1,200 feet (366 m). An angular unconformity marks the contact of the deformed Mesozoic strata with the overlying Paleocene South Park Formation north of the Middle Fork South Platte River. The folds appear to be early Laramide features because there is no evidence of similar deformation in the overlying South Park Formation.

Santa Maria fault is a north- to northwest-trending fault on the east side of the hogback held up by Mesozoic strata heading northwest from the town of Hartsel. It has approximately 1,500 ft (457 m) of displacement, east side down, and may join the Hartsel Springs fault. Juxtaposition of Dakota Sandstone against Pierre Shale with less displacement in the South Park Formation suggests early Laramide deformation. Later movement is indicated by juxtaposition of Dakota Sandstone against Oligocene Antero Formation. Neogene displacement is difficult to estimate without a thickness of the Antero Formation, but it may be on the order of 100 to 200 ft (30 to 60 m).

South Park, McDannald, and San Isabel thrust faults are concealed by Quaternary deposits that head to the north-northwest through the central part of the quadrangle interpreted chiefly by seismic and deep borehole data to be imbricate, west-verging thrusts with thousands of feet of horizontal displacement (Stark and others, 1949; Clement and Dolton, 1970; N. Sterne, written communication, 2016). They displace Upper Cretaceous strata above Paleocene South Park Formation suggesting middle to late Laramide timing of deformation.

Hartsel anticline is an anticline formed on the hanging wall of the San Isabel thrust fault that has approximately 500 to 700 ft (150 to 213 m) of amplitude. It deforms Upper Cretaceous Fox Hills Sandstone and Pierre Shale.

Mud Springs fault is marked by a belt of deformation crossing the northeast corner of the quadrangle interpreted to be a thrust similar to the South Park, McDannald and San Isabel thrusts, but heretofore unnamed. It is evident at the surface at its southern extent in the quadrangle but appears to become a blind thrust beneath folded strata at its northern extent.

Muley Gulch anticline is a tight fold crossing the northeast corner of the quadrangle formed on the hanging wall of the Mud Springs fault. Its east limb is steeply dipping and the fold may be deformation above a blind splay off of the Mud Spring feature.

San Isabel syncline is a syncline on the hanging wall of the San Isabel thrust east of the Hartsel anticline that deforms Paleocene South Park Formation with approximately 500 to 700 ft (150 to 213 m) of amplitude.

Currant Creek fault is a northwest trending fault crossing the Hartsel uplift in the southern part of the quadrangle. It juxtaposes Precambrian rocks and Mesozoic strata against Oligocene Antero Formation indicating Neogene movement. Neogene displacement is difficult to estimate without a thickness of the Antero Formation but it may be on the order of 200 to 300 ft (60 to 91 m).

Deformation from compressional tectonism during the Laramide orogeny occurred along most of the structures present in the quadrangle. Early deformation preceded deposition of the Paleocene South Park Formation and stratigraphic relationships within the unit point to early uplift to the west. Clast succession in the lower volcaniclastic member of the South Park Formation reflects unroofing of volcanic centers and Paleozoic rocks from an early Sawatch-Mosquito high in the west. Decrease in grain size from a conglomerate with boulders as large as up to 8 ft (2.4 m) on Reinecker Ridge to 2 ft (0.6 m) in the east part of the quadrangle suggests powerful streams and a close western source. Uplift on the west side of the Santa Maria fault north of Hartsel and the southwest side of the inferred Hartsel Springs fault may have accompanied this phase of Laramide deformation. Offsets of the Upper Cretaceous marine sediments along the Hartsel fault indicate recurring movement along this feature.

A period of erosion and deformation followed this earlier Laramide phase before deposition of the South Park Formation. The north-plunging Badger Springs folds appear to have formed during this early phase of the Laramide event because they are truncated by the angular unconformity at the base of the South Park Formation. The angular unconformity cuts deeper into the upper Cretaceous strata in a northwesterly direction indicating there was considerable uplift and deformation farther to the northwest prior to deposition of the South Park Formation. Deformation, dominated by the west-directed Elkhorn thrust fault east of the quadrangle and development of the South Park, McDannald, San Isabel, and Mud Springs thrust faults, appears to have accompanied deposition of upper members of the South Park Formation. Folding of the Hartsel anticline, San Isabel syncline, and Muley Gulch anticline may have accompanied this phase. This style of west-directed compressional deformation continued after deposition of the South Park Formation. Compressional deformation between the rising Hartsel anticline and San Isabel thrust caused a series of east-directed small-scale back-thrusts evident in a northwest trending belt northeast of Hartsel. The earlier uplifts along the Santa Maria and Hartsel faults, may have buttressed the later west-directed deformation leading to complex patterns of deformation in this belt. A number of northeast-trending faults segment the main structures; many may be tear faults in the hanging walls of the thrust sheets. The Hartsel fault has a similar northeast trend and may have been reactivated as a tear fault during Laramide compression.

Several faults drop blocks containing the Oligocene Antero Formation in a broad north-to-south trending belt though the center of the quadrangle. It appears that this phase of extensional tectonism may have reactivated older features. The Santa Maria and Currant Creek faults appear to be part of the same fault system showing downward displacement on the east side.

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[1]Age assignments follow the International Commission on Stratigraphy International Chronostratigraphic Chart v. 2017/02 (Cohen and others, 2013; updated)

COLORADO GEOLOGICAL SURVEY
COLORADO SCHOOL OF MINES