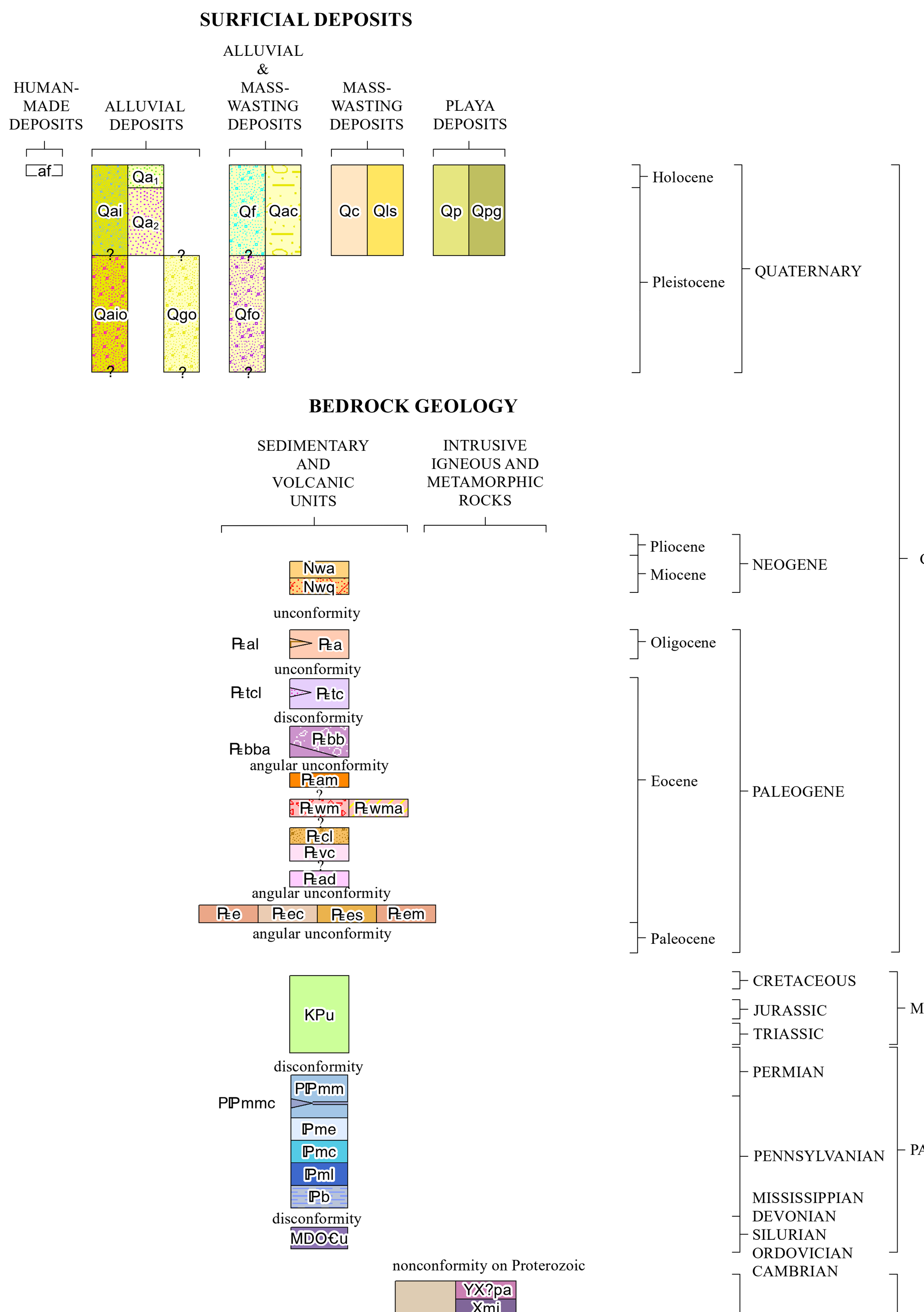
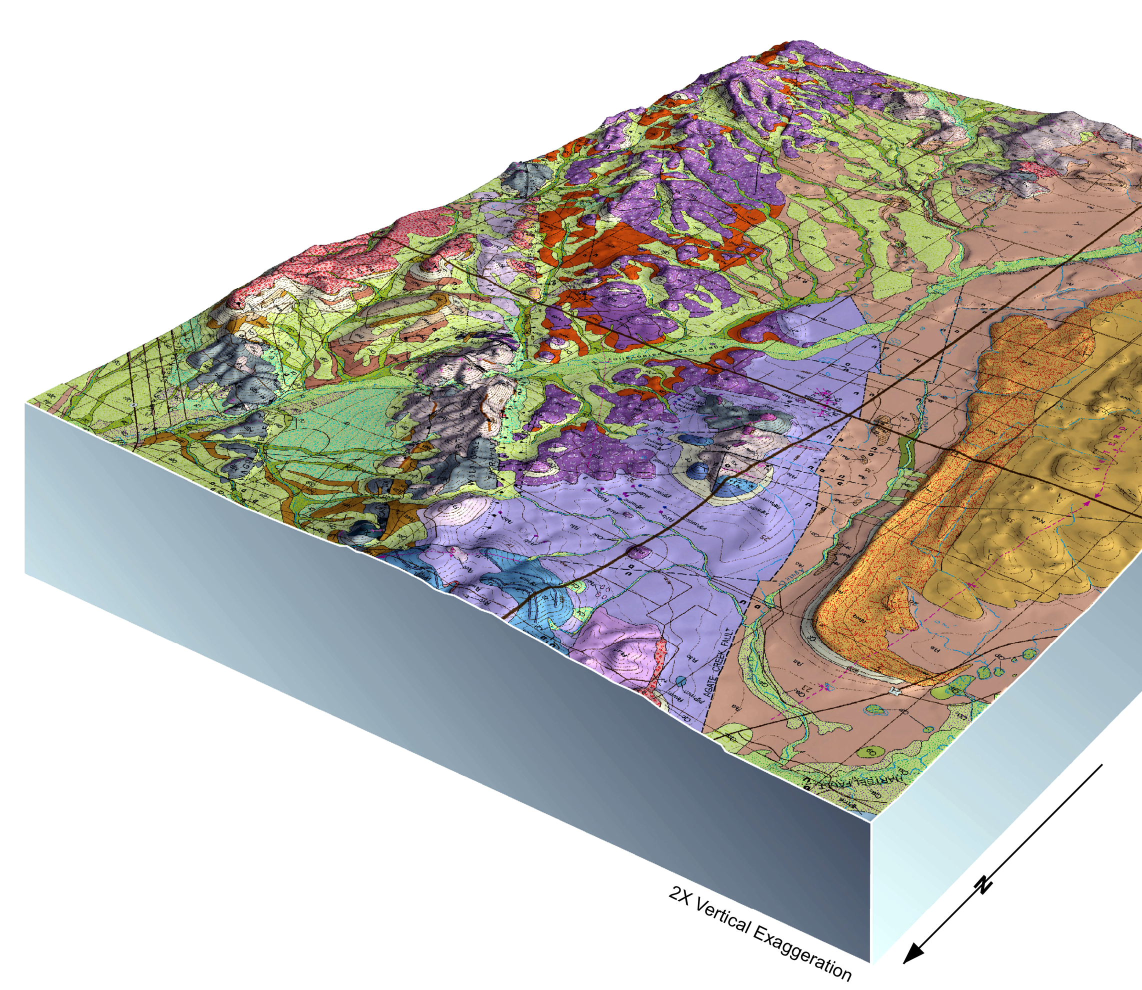
COLORADO GEOLOGICAL SURVEY
COLORADO SCHOOL OF MINES
GOLDEN, COLORADO

CORRELATION OF MAP UNITS



3-D OBLIQUE VIEW



GEOLOGIC SETTING

Regional Setting
The Antero Reservoir NE quadrangle straddles the western edge of the Hartsel uplift within the complex South Park Laramide structural basin. Generally, the basin can be described as an east-dipping downwarp bounded by two northwest-trending uplifts: the Sawatch uplift to the west and the Front Range uplift to the east. The Hartsel uplift is a westward-jutting structural salient of the Front Range uplift that brings Proterozoic rocks further into the basin south of the town of Hartsel. The uplift itself has been segmented into a series of smaller internal uplifts and basins by Paleogene faulting along a series of northwest trending faults. The quadrangle also spans the Late Paleozoic boundary between the central Colorado trough (DeVoto, 1972) to the west and the Frontrangia uplift to the east (Mallory, 1958).

Stratigraphy and Structural Evolution of the Area
Precambrian intrusive igneous rocks are exposed at the surface within the Hartsel uplift, coring several fault-bound highlands. The dominant unit is biotite-rich, porphyritic granite-quartz monzonite (Xgp) as well as smaller exposures of equigranular granite and alkali feldspar granite (Xg). Pegmatite and aplite dikes (XYp) are common, and there are several mafic dikes (Xmi) in the Wildhorse Hills. Crosscutting relationships in places suggest that the granite-quartz monzonite is younger than the equigranular granite. Age of the alkali feldspar granite relative to the dominant granite-quartz monzonite is uncertain but it often occurs as small isolated knobs within the granite-quartz monzonite suggesting that it is younger. Shear zones cross-cut the intrusive rocks with a dominant east to northeast orientation. Many of the shear zones (YXc) are characterized as linear bands of well-developed foliation within the typically massive to weakly foliated plutonic rocks. These shear zones are interpreted to have Paleoproterozic to Mesoproterozioic origins. Several of the mafic dikes follow the foliated shear zones, and are in turn foliated in places, indicating that they followed the active zones of weakness.

The Pennsylvanian to Permian (?) Minturn and Maroon formations (ℙPmm and ℙPmmc) were deposited as sediments in the central Colorado trough concurrent with uplift of Frontrangia during the ancestral Rocky Mountain orogeny. On the west limb of the Antero syncline, several thousand feet of Paleozoic rocks are present. The Minturn Formation includes an evaporite facies (ℙme) that is exposed north of the Hartsel fault in the northwest corner of the quadrangle, and west of the Antero syncline on the Antero Reservoir quadrangle (Kirkham and others, 2012). The evaporite facies is subject to dissolution and local formation of karst features. East of the Agate Creek fault, and north of the Poyner Ranch fault, a few hundred feet of undifferentiated upper Minturn Formation, and possibly lower Maroon Formation, are in depositional contact with Proterozoic rocks. The Minturn evaporite facies and the other Paleozoic rocks below it were not observed. These stratigraphic relationships indicate that the Hartsel uplift was actively rising during deposition of the Minturn and Maroon formations, and that it formed parts of the western edge of Frontrangia at that time.

Younger Paleozoic and Mesozoic formations found elsewhere within the South Park structural basin have been removed by erosion from the Hartsel uplift. Stratigraphic relations in the Mesozoic formations observed further to the north indicate that the Mesozoic formations must have covered the Hartsel uplift at one time but were removed during, or after, the Laramide orogeny. The Laramide orogeny began in the Late Cretaceous and continued into the Eocene (Raynolds, 1997) as a period dominated by compressional deformation. The limited exposures of Paleozoic rocks on the quadrangle are strongly folded and tilted as a consequence of Laramide compression. The South Park Formation, which represents the synorogenic sediments deposited in the South Park Basin during the early Laramide orogeny, is not present within this quadrangle, evidence that the Hartsel uplift was a positive feature during much of the Laramide event.

Near the end of the Laramide orogeny, the Hartsel uplift was segmented into several internal basins and uplifts. Sediments, mapped as the Echo Park Alluvium (Ᵽes, Ᵽem, and Ᵽec), accumulated in coalescing alluvial fans within the active basins as they developed. The sediments are dominated by material derived locally from the uplifts. The formation includes arkosic sandstone with abundant pebble conglomerate, and mudstone. The mudstone is interpreted to be overbank and sheetwash deposits (Chapin and Cather, 1983). The sandstone contains abundant volcaniclastic debris. Detrital zircons from a sample of the sandstone fell in a distribution with a high concentration of ages between 62 and 79 Ma with the youngest crystal age of 52 Ma (M. Schmitz, Boise State University, written communication, 2017). This suggests a sediment source with abundant Late Cretaceous to early Eocene volcanic rocks. Similar aged volcanic rocks have not been identified in the map area but are found within the South Park Formation further to the north (Barkmann and others, 2017; Kirkham and others, 2006). This suggests an axial stream system that brought sediments from the north to be joined by alluvial fans carrying local sediment. A conglomerate containing abundant Paleozoic carbonate clasts marks the top of the Echo Park Alluvium suggesting an influx of coarser grained material likely from a local source. Deformation of the Echo Park Alluvium by the Rocky Top reverse fault in the north-central part of the quadrangle indicates that the tectonic style of deformation following, and possibly during, deposition of the Echo Park Alluvium continued to have a compressional component well into the Eocene. Chapin and Cather (1983) originally suggested that the Echo Park Alluvium represented a change from east-northeast compression to right-lateral wrench faulting.

Tectonism continued after the Laramide orogeny but was characterized by widespread volcanism accompanied by faulting and erosion. A prolonged period of broad erosion is believed to have led to beveling of the landscape with a generally east to northeast directed drainage pattern (Epis and others, 1976). Rock units in the Hartsel area record volcanism accompanied by fluvial and lacustrine sedimentation commencing on or just before 38 Ma and continuing to approximately 33 Ma. Volcanic rocks within this quadrangle include andesitic flows (Ᵽad) and volcaniclastic sediments (Ᵽvc). The andesitic flows are similar to those found in the Garo quadrangle (Kirham and others, 2007) and in the Buffalo Peaks (Houck and others, 2012) suggesting a northwest source for these early volcanic rocks. High energy fluvial systems filled paleo-valleys with boulder conglomerates (Ᵽcl) derived from the west. The Wall Mountain Tuff (Ᵽwm and Ᵽwma) signals large-scale silicic volcanism to the west approximately 37 Ma that blanketed the region with extensive ignimbrite flows with the thickest accumulations in paleo-valleys above the earlier boulder conglomerate deposits. Andesitic volcanism continued following the Wall Mountain Tuff event as recorded by flows and lahar deposits (Ᵽam). This andesitic pulse of volcanism, which occurred at approximately 34.4 Ma, was previously mapped as Thirtynine Mile andesite by (DeVoto, 1971) with a possible source to the south-southeast. A prominent rhyolitic volcanic breccia (Ᵽbb and Ᵽbba) from an unknown source, dated at 34.3 Ma, caps the andesitic rocks and extends further to the south. It includes ignimbrites and lahars that were deposited over the eastern and central parts of the quadrangle. High energy fluvial systems continued to fill paleo-valleys with arkosic sediment and boulder conglomerates (Ᵽtc) derived from the west. Local ponding on interfluves deposited mudstone and limestone (Ᵽtcl).

Disrupted drainage patterns and renewed silicic volcanism to the southwest led to accumulation of very tuffaceous fluvial and lacustrine sediments of the Antero Formation (Ᵽa and Ᵽal). These sediments are slightly younger than 34.2 Ma (Kirkham and others, 2012) and appear to cover a landscape with relatively high relief carved into the older volcanic and Precambrian rocks. A major paleovalley is present in the lower part of the Antero Formation on the west side of the Agate Creek fault, in the southwest part of the quadrangle. It is filled with cobbly fluvial deposits and lahar deposits, and appears to be oriented parallel to the fault. The northward decrease in size and abundance of conglomerate clasts suggests a southern source. This interpretation is in agreement with that of McIntosh and Chapin (2004), who concluded that the volcanic material in the Antero Formation came from Mt. Aetna, and that most of the ignimbrite deposition occurred due south of the Antero Reservoir NE quadrangle. Lacustrine deposits, including limestone and tuffaceous shale, occur in the middle and upper parts of the formation. The uppermost part of the formation also contains a few lens-shaped deposits of conglomerate.

Faulting accompanied the volcanism along a network of north to northwest trending faults crosscut by east to northeast trending faults. Many of the faults within the central part of the quadrangle do not appear to offset the Antero Formation, indicating that much of this deformation quieted down by the Oligocene. This deformation included continued movement on the Agate Creek reverse fault, which, in contrast to the smaller faults to the east, does offset the Oligocene Antero Formation. Although many authors have described examples of Neogene extensional faulting throughout South Park (Stark and others, 1949; De Voto, 1971; Scarbrough, 2001; and Ruleman and others, 2011), the late Paleogene or early Neogene style of faulting evident within the Hartsel uplift does not fit the extensional model in that it includes apparent reverse displacements. As previously described, Chapin and Cather (1983) suggested that the tectonism during deposition of the Echo Park Alluvium was dominated by wrench faulting. The pattern of faulting seen within this quadrangle suggests continued wrench faulting into the Oligocene.

Units Ᵽwq and Ᵽwa are correlated with the Wagontongue Formation, which is late Miocene in age (DeVoto, 1971). Their cobble and boulder conglomerates indicate a very high-energy fluvial system. The southward decrease in size and abundance of conglomerate clasts, as well as the clast compositions, suggest a northern source. The upward transition from a quartzite lithofacies to an andesite lithofacies suggests a change in the source area during deposition of the formation. Deformation of the Wagontongue Formation in the Antero syncline indicates the syncline was active well after deposition of this fluvial unit.

Quaternary deposits include alluvium along modern streams (Qa_1 and Qa_2). Only the South Fork South Platte at the northwest corner of the quadrangle is perennial and may include glacial outwash. 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 on steeply sloping surfaces (Qf and Qfo). Much of the region is blanketed with colluvium and alluvial deposits (Qc, Qac) with older deposits mantling strath pediment surfaces over exposed bedrock above modern streams (Qgp). These older gravel deposits also fill abandoned channels above modern drainages as inverted topography. Several small landslides (Qls) have developed below the Wall Mountain Tuff (Ᵽwm) with the underlying Echo Park Alluvium (Ᵽe) serving as a weak layer. Many small natural depressions filled with playa deposits (Qp) dot the landscape. Formation of these depressions is enigmatic, but most occur where the Antero Formation (Ᵽa) is at or near the surface and many occur in areas where Pennsylvanian Minturn Formation evaporite beds may occur at a greater depth. Hypotheses for their origin include wind erosion of unconsolidated tuffaceous material from the Antero Formation, dissolution of limestone in the Antero Formation, or dissolution of evaporite from the Minturn Formation forming karst features. Gypsiferous lacustrine playa deposits (Qlg) on the east limb of the Antero Syncline may have precipitated from gypsum-rich fluids migrating up from Minturn Formation evaporites along local faults.

Agate Creek currently flows to the north-northwest to join the South Fork South Platte and drains much of the central and southern half of the quadrangle. The map patterns of alluvium Qa_1 and Qa_2 indicate that at one time much of the main course flowed to the northeast following a path, informally named Agate Creek paleovalley on Plate 1, that cuts a deep notch through the informally named Wildhorse Hills uplift. At the point where the new channel splits north from the old, the two channels are at the same elevation. This, combined with the continuous extent of Holocene and Late Pleistocene alluvium (Qa_1) as a continuous band from the active channel through the paleovalley suggests that stream piracy may have been as recent as Holocene. Older alluvium (Qa_2) on terraces along the active channel below the point of piracy may have been derived from a smaller watershed.

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

Hartsel uplift underlies much of the east side of the quadrangle where Precambrian crystalline bedrock is exposed at the surface in what is, in part, a Laramide feature. Stratigraphic relations in the Minturn and Maroon Formations indicate that it was also part of the late Paleozoic Frontrangia highland during much of its history.

Hartsel fault trends northeasterly through the very northwest corner of the quadrangle and is the northern boundary of the Hartsel uplift. Stratigraphic and structural relations indicate that it was active during the late Paleozoic ancestral Rocky Mountains orogeny as well as the late Mesozoic to early Cenozoic Laramide orogeny. It is a high-angle fault with displacement that may exceed 9,000 ft (2,736 m).

Currant Creek fault is a northwest trending fault crossing the Hartsel uplift in the northeastern corner of the quadrangle. It juxtaposes Precambrian rocks against Mesozoic and Cenozoic rocks indicating Cenozoic movement. Displacement is estimated to be at least 200 ft (61 m).

Wagonwheel fault is an inferred fault placing Precambrian crystalline rock over Eocene Echo Park Alluvium in the north-central part of the quadrangle. It is informally named herein after the pattern of roads in the Hartsel Springs subdivision just to the west of its trace. It is inferred to be a reverse fault because of similar setting and probable age as the Rocky Top fault and has an estimated displacement of up to 550 ft (168 m). It may be concealed beneath the Wall Mountain Tuff (Ᵽwm) further to the southeast. To the northwest it may be difficult to identify where it extends into Proterozoic rocks.

Rocky Top fault is a reverse fault placing Precambrian crystalline rock over Eocene Echo Park Alluvium exposed in one of the uplifted blocks in the north-central part of the quadrangle. It is informally named herein after a local ranch. Displacement is estimated to be up to 500 ft (152 m). It cannot be followed to the southeast of the Poyner Ranch fault. The fault is either concealed, or its strain may have been translated along the Poyner Ranch fault to a similar fault outside of the map area. To the northwest it may be difficult to identify where it deforms mostly Paleozoic strata with poorly exposed marker beds.

Thirtyone Mile-Buffalo Gulch fault bounds the west side of the largest uplifted, Precambrian-cored block in the north-central part of the quadrangle. The informal name is from a regional tectonic map (Figure 3) of Scarbrough (2001). It is a normal fault that places Precambrian granite against Eocene volcanic rocks with an estimated displacement of at least 1,000 ft (305 m). In many areas the fault is concealed by Quaternary deposits but there are exposures of fault breccia and fault planes with slickenlines scattered along its trace.

Agate Creek fault trends north to northwest through the west-central part of the quadrangle. It is a high-angle reverse fault with at least 5,500 ft (1,672 m) of offset. Several thousand feet of Paleozoic rocks are present on the west side of the fault, but absent, or very thin, on the east side. Eocene and Oligocene rocks are present on both sides of the fault, but are much thicker on the west side. Miocene rocks are present only on the west side of the fault. This is interpreted to mean that the Agate Creek fault bounds the west side of the Laramide uplift, and that it experienced major up-to-east movements during the Laramide orogeny. It may have also bounded portions of the west side of the Frontrangia uplift during the ancestral Rocky Mountain orogeny, although this isn't known with certainty. It experienced minor up-to-east movements during the Eocene and Oligocene epochs, and possibly afterward as indicated by displacement of the Oligocene Antero Formation (Ᵽa). These conclusions are in agreement with those of DeVoto (1971). The Agate Creek fault is segmented by numerous cross-faults that may have moved contemporaneously with it, or they may have moved after its latest episode of movement.

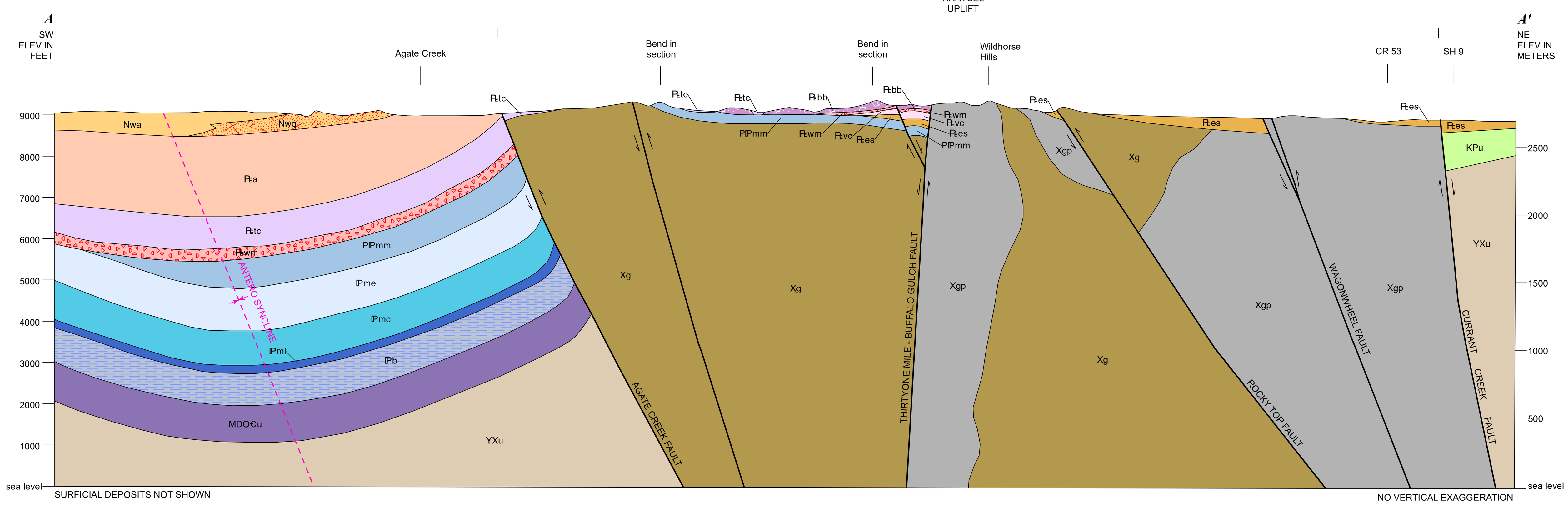
Antero syncline may have formed in part in response to movement of the Agate Creek fault. Also, evaporites in the Minturn Formation may have dissolved and/or migrated out of the syncline, increasing its subsidence and altering its appearance (Kirkham and others, 2012). The Miocene Wagontongue Formation is deformed by the Antero syncline indicating Neogene deformation.

Poyner Ranch fault is a northeast-trending fault informally named herein after the Poyner Ranch in the center of the quadrangle. It is one of many faults with similar orientations that offset the prevailing north to northwest regional structural trend. This fault offsets the Agate Creek fault that bounds the Hartsel uplift almost 2 mi (3.2 km). Further to the northeast it bounds the southeast ends of two Precambrian-cored uplifts. It is considered a compartmental fault in that it is a through-going feature along which the sense of displacement may change from structural block to structural block. A small exposure of the lower volcaniclastic unit (Ᵽvc) is preserved in the saddle on the Paleoproterozoic granite (Xg) in sec. 33, T.12S., R.75W. at an elevation of approximately 9,120 ft (2780 m). This isolated outcrop is approximately 100 ft (30 m) higher than exposures south of the Poyner Ranch fault indicating at least 100 ft (30 m) of displacement after deposition of that unit (Eocene).

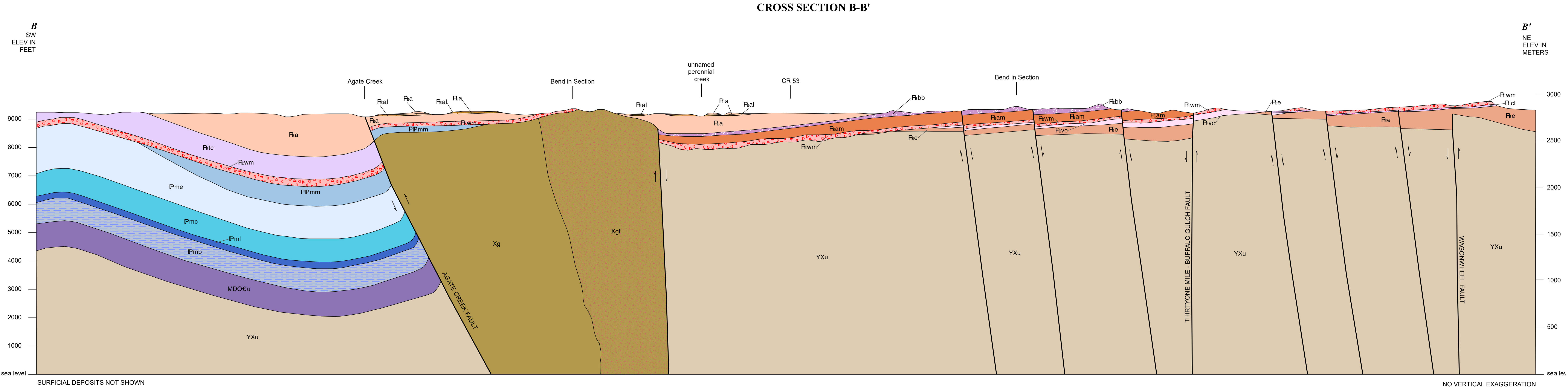
Other faults include a network of north to northwest-trending faults that deform the Eocene volcanic and sedimentary rocks across much of the eastern half of the quadrangle. Displacement on the northwest trending faults is on the order of 20 to 100 ft (6 to 30 m) and is typically east side down. Few of these faults seem to carry into the younger Oligocene Antero Formation indicating movement only into the Eocene. A series of northeast-trending faults crosscut the dominant northwest-trending set and often appear to transfer strain of the latter faults to other locations as a type of compartmental fault.

Precambrian shear zones are linear bands of deformation exposed in many areas of the Proterozoic cores of the uplifted blocks throughout the quadrangle. Many of the bands of deformation continue for some distance. Deformation of the otherwise massive to weakly foliated plutonic host rocks is evident as either localized bands of very strongly foliated plutonic rock, or bands of granulated rock that often resembles quartzite interpreted to be a form of cataclasite. Many of the bands of deformation in the Proterozoic rocks trend in a northeasterly direction similar to the compartmental faults that deform the overlying Cenozoic volcanic and sedimentary rocks. Also, some of the shear zones coincide with faults that offset Paleogene rocks. This indicates that many of the older shear zones in the Proterozoic basement were reactivated during subsequent periods of deformation.

CROSS SECTION A-A'



CROSS SECTION B-B'



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GEOLOGIC MAP OF THE ANTERO RESERVOIR NE QUADRANGLE, PARK COUNTY, COLORADO
CORRELATION OF MAP UNITS, 3-D OBLIQUE VIEW, GEOLOGIC HISTORY, AND CROSS SECTIONS

By Peter E. Barkmann, Karen J. Houck, Katheryne McGee, and Daniel P. Miggins

2018

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