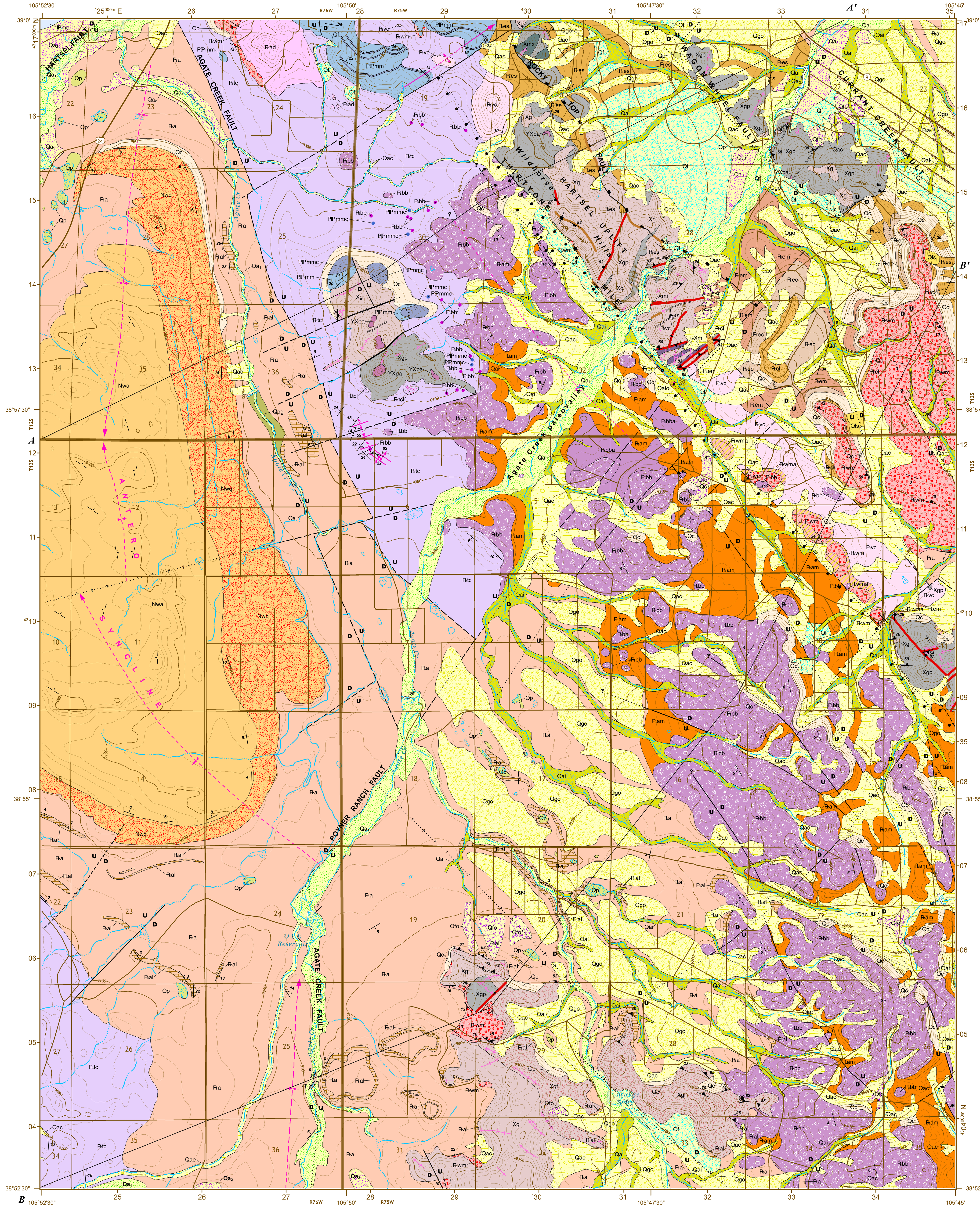
COLORADO GEOLOGICAL SURVEY
COLORADO SCHOOL OF MINES
GOLDEN, COLORADO

GEOLOGIC MAP OF THE ANTERO RESERVOIR NE QUADRANGLE
PARK COUNTY, COLORADO
OPEN-FILE REPORT 18-05
PLATE 1 OF 2



Coordinate System: NAD 1983 UTM Zone 13 North
Projection: Transverse Mercator
Datum: North American 1983

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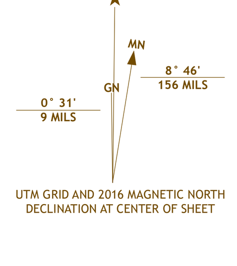
Roads....U.S. Census Bureau, 2015-2016
Names....GNIS, 2016
Hydrography....National Hydrography Dataset, 2013
Contours....National Elevation Dataset, 2002
Boundaries....Multiple Sources; see metadata file, 1972-2016
Public Land Survey System....BLM, 2011
Wetlands....FWS National Wetlands Inventory, 1977-2014



UTM GRID AND 2016 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:24,000

CONTOUR INTERVAL 20 FEET

QUADRANGLE LOCATION

Garo	Hartsel	Sulphur Mountain
Antero Reservoir	Antero Reservoir NE	Guffey NW
Castle Rock Gulch	Agate Mountain	Dicks Peak

ADJOINING QUADRANGLES

This mapping project was funded jointly by the Colorado Geological Survey and the U.S. Geological Survey through the National Cooperative Geologic Mapping Program under STATEMAP agreement G17AC00259.

GEOLOGIC MAP OF THE ANTERO RESERVOIR NE QUADRANGLE, PARK COUNTY, COLORADO

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DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSITS

HUMAN-MADE DEPOSITS

af **Artificial fill (uppermost Holocene)** — Unsorted sand, silt, gravel, and/or rock fragments locally used as fill; includes fill used for dams, channelization, highway embankments and railroad grades. Depending on age, construction, location, aspect, and material, these deposits may be prone to slope failure and differential settlement. Maximum thickness is approximately 25 ft (7.6 m).

ALLUVIAL DEPOSITS

Qai **Alluvium of intermittent drainages (Holocene and Upper Pleistocene)** — Unsorted and unstratified to stratified clay, silt, sand, and gravel of varying color depending on source area deposited during sudden high-energy, high-volume storm events in intermittent tributary drainages. It is commonly found beneath well defined, narrow channels. Clast compositions and sizes vary depending on units exposed in the watershed; some boulders may reach 6 ft (2 m) in diameter. Contains locally derived angular to subangular clasts. Locally includes distinct fan-shaped deposits. May transmit limited groundwater. Areas underlain by these deposits are prone to flooding and to collapse. Some areas may also be prone to debris flows. Thickness is estimated to be 5 to 20 ft (1.5 to 6 m).

Qaio **Old alluvium of intermittent drainages (Middle and lower Pleistocene)** — Unsorted and unstratified to stratified clay, silt, sand, and gravel similar to Qai but found on high terraces above modern drainages. Clast compositions and sizes vary depending on units exposed in the watershed. Contains locally derived angular to subangular clasts. Thickness is estimated to be 5 to 10 ft (1.5 to 3 m).

Qa₁ **Stream alluvium one (Holocene)** — Mainly poorly sorted, clast supported, unconsolidated, gray to tan, sandy gravel of all sizes. Includes gravelly sand, silty sand, and sandy silt in modern channels, floodplains, and underlying adjacent low-lying terraces that are approximately 5 ft (1.5 m) or less above modern perennial and main intermittent channels. Most deposits in alluvium one are stratified and may have cut-and-fill channels. The unit generally has little to no soil horizon development, although beds of organic-rich sediment or peat are locally present. Clasts are subrounded to subangular and rarely round or angular. Clast composition is polymictic, dominated by quartzite, sandstone, and felsic and intermediate igneous rocks with lesser amounts of granite and gneiss. Sediment in main intermittent drainages is transported during flood events and may locally include matrix-supported debris with large clasts up to 3 ft (1 m). Hydraulically connected to streams, and groundwater is typically very close to the surface. Areas underlain with this unit are prone to frequent, seasonal flooding, and collapse. Thickness of the unit is estimated to range from about 3 to 15 ft (1 to 5 m) but may be greater in places.

Qa₂ **Stream alluvium two (Upper Pleistocene)** — Alluvium two contains stratified, poorly sorted, clast supported, sandy cobble and pebble gravel, gravelly sand, silty sand, and sandy silt. Clast composition is similar to that of alluvium unit one. Streams are incised about 5 to 15 ft (1.5 to 4.6 m) into alluvium two and there may be Bk soil horizons with Stage I carbonate development up to 3 ft (1 m) thick (Machette, 1985). Areas underlain by this unit are prone to occasional flooding and collapse. The unit is a local source of gravel. Thickness of the unit is estimated to range from about 3 to 15 ft (1 to 5 m) but may be greater in places.

Qgo **Old gravel deposits (Middle and lower Pleistocene)** — Poorly to moderately sorted, sandy, pebble- to cobble-sized alluvial gravel deposited on gently sloping bedrock surfaces (pediments) and old channels elevated above modern drainages. May include old alluvial, sheetwash, and colluvial deposits. Clasts are rounded to subrounded and composition depends on bedrock exposed in the source watershed. Incision by modern streams through these deposits has resulted in benches with bedrock exposed in the faces that rise up to 50 ft above modern drainages. Some of the benches may be extensive elevated surfaces and others small isolated knobs or linear ridges representing former stream courses that are now inverted and left as high areas in the landscape. Hydraulically disconnected from streams and typically unsaturated. The unit is a local source of gravel. Thickness may be up to 10 ft (3 m). Steep areas below these deposits may be prone to rockfall.

ALLUVIAL AND MASS-WASTING DEPOSITS

Qf **Fan deposits (Holocene and Upper Pleistocene)** — Deposits beneath geomorphically distinct fans at the mouths of tributary valleys deposited as distributive alluvial channels. Fan deposits are chiefly poorly sorted, moderately stratified, clast-supported sandy gravel and gravelly sand of varying color depending on source area deposited as alluvium during storm events. Locally, they include debris-flow deposits that are composed of matrix-supported, poorly sorted, silty or sandy gravel. In some areas, the deposits from adjacent valleys merge to form coalescing fan complexes. Clasts contained in fan deposits are mainly subangular to angular. Areas underlain by fan deposits are prone to slope instability, hydrocompaction, flooding, and debris flows. Maximum thickness of fan deposits is estimated at 25 ft (7.6 m).

Qfo **Old fan deposits (Middle and lower Pleistocene)** — Deposits similar to unit Qf in geomorphically distinct fans that are found on benches above the modern tributary valleys. These benches sit at least 10 to 20 ft (3 to 6 m) above active channels incised into the older feature. Depending on degree of incision by modern drainages, areas underlain with these deposits may be unstable. Maximum thickness of fan deposits is estimated at 25 ft (7.6 m).

Qac **Alluvium and colluvium deposits, undivided (Holocene and Upper Pleistocene)** — This unit consists of several components of varying color depending on source area: (1) alluvial sediments in local channels, floodplains, low terraces, and small tributary drainages, (2) alluvial sediments forming small coalescing alluvial fans on slopes below ridges and hills, (3) sheetwash deposits along valley margins and shallow hillslopes, and (4) colluvium on gentle hillslopes. The components are mapped as a single unit where two or more grade laterally from one to another with differentiation not appropriate for this map scale. The alluvial component of the unit is very poorly to well sorted and ranges from sandy pebble, cobble, and boulder gravel to stratified fine sand and silt. Clasts in the alluvial component are subangular to subrounded. The colluvial part consists of very poorly sorted, unstratified or poorly stratified, gravelly to silty sand, sandy to silty gravel, and gravelly sandy silt. Clasts in the colluvial part are chiefly angular to subangular. The unit may locally include debris-flow deposits, which typically are matrix-supported gravelly silt, and may also contain landslides or soil slips. Loess deposits are commonly interbedded within the unit. In a few areas, these deposits may be heavily burrowed. Thickness of the unit is estimated to range from 3 to 20 ft (1 to 6 m). Areas underlain with this unit are prone to flooding, debris flows, and hydrocompaction.

MASS-WASTING DEPOSITS

Qc **Colluvium (Holocene and Upper Pleistocene)** — Includes deposits of poorly sorted, sandy or silty, fine to coarse gravel, gravelly sand, and gravelly silt on, or at the base of, hillslopes. The unit is derived locally and transported distances of tens of feet or less, contains clasts of varying size, has little or no sedimentary structures or stratification, but may include minor amounts of sheetwash and debris-flow deposits. Colluvium may be rich in boulders below cliffs and rocky outcrops and may locally include landslide, talus, or rockfall deposits. Clasts in colluvium are typically angular to subangular, except where sourced in bedrock or surficial deposits that contain well-rounded clasts. Areas mantled by colluvium are prone to continued colluvial deposition, rockfall, debris flows, and slope failure. Maximum thickness of colluvium is estimated to be 20 ft (6 m).

Qls **Landslide deposits (Holocene and Upper Pleistocene)** — Recent landslide deposits consisting of heterogeneous, mostly unsorted and unstratified rock and soil debris that is commonly characterized by hummocky topography with well-defined headscarps and toes. Areas adjacent to landslide deposits are prone to additional slope failures. The mapped landslides may be between 10 and 20 ft (3 and 6 m) in thickness and are composed of upland bedrock materials.

PLAYA DEPOSITS

Qp **Playa deposits (Holocene and Upper Pleistocene)** — Light-gray, very calcareous mud, silt, and very fine sand in laminae and thin beds ¼ to 1 in (0.6 to 2.5 cm) thick. Laminae of calcite crystals, formed by evaporation of lake water, may also present. Beds of organic-rich sediment or peat are locally present. On the quadrangle, playa deposits occur in shallow natural depressions. Thickness is unknown but is likely less than 7 ft (2 m). May be saturated with groundwater depending on season and precipitation patterns. Areas underlain by this unit are prone to flooding, dissolution, and hydrocompaction.

Qpg **Playa gypsum deposits (Holocene and Upper Pleistocene)** — Deposits of light-gray, sand-sized gypsum crystals occur in a dry lake bed along Agate Creek in sec. 36, T. 12 S., R. 76 W., and sec. 1, T. 13 S., R. 76 W. Cryptogamic soil occurs on the surface of the deposits and numerous shallow sinkholes are present. Sinkholes are up to 8 ft (2 m) wide and 3 ft (1 m) deep. In some places, coalesced sinkholes form narrow closed depressions up to 100 ft (30 m) long. The thickness of the deposits is unknown, but is probably less than 6 ft (2 m). Area underlain by this unit is prone to flooding, dissolution, and collapse. Soils formed on this unit are likely to be corrosive.

BEDROCK GEOLOGY

Bedrock unit classifications follow guidelines compiled in the American Geological Institute Geoscience Guidebook (Walker and Cohen, 2006). Specifically, igneous rocks are classified by the International Union of Geological Sciences (IUGS) standards; volcanic rock classification is by total alkali-silica (TAS) diagram analysis.

SEDIMENTARY AND VOLCANIC ROCKS

Wagontongue Formation (Miocene)

Nwa **Wagontongue Formation andesite lithofacies** — Reddish-brown conglomeratic sandstone and conglomerate, poorly lithified and poorly exposed. The sandstones and conglomerates are poorly sorted, and are dominated by rounded to subrounded cobbles and small boulders <2 ft. (0.6 m) in diameter of andesite. Clasts of welded tuff and basalt were also observed. Cobbles and boulders decrease in the southward direction. The andesite lithofacies forms low hills along the axis of the Antero syncline. The maximum thickness of the entire Wagontongue Formation is about 600 ft (183 m). The unit is prone to rockfall on steep slopes.

Nwq **Wagontongue Formation quartzite lithofacies** — Tan to grayish-brown conglomeratic sandstone and conglomerate, poorly lithified and poorly exposed. In the limited exposures, the sandstones and conglomerates are clast supported and bedded or crossbedded in sets 6 to 12 in (15 to 30 cm) thick. They are poorly sorted, and are dominated by rounded cobbles of quartzite. Cobbles of vein quartz, intrusive igneous rocks, metamorphic rocks, chert, and andesite were also observed. Cobbles decrease in the southward direction. The quartzite lithofacies is more resistant to erosion than either the underlying Antero Formation or the overlying andesite lithofacies. It forms a high ridge around the eastern side of the doubly plunging Antero syncline, but pinches out toward the northwest. The thickness of the quartzite lithofacies may be up to 400 ft (122 m). The Wagontongue Formation is separated from the underlying Antero Formation by an angular unconformity. The unit is prone to slumping and rockfall on steep slopes.

Antero Formation (Oligocene)

₮a **Antero Formation** — White to light-gray shale, sandstone, conglomerate, and limestone that is composed mostly of reworked volcanic ash and pumice clasts. It is dominantly coarse grained in the southwestern part of the map area, and fine grained in the northwestern part. In the central-southeastern part of the map area it is dominated by fine-grained material that grades into coarse-grained material at the edges near the depositional contacts with underlying bedrock. Five different lithofacies were observed in the field but are mapped as one unit. *Tuffaceous shale* includes laminated siltstone and shale. At one locality, mm-wide invertebrate trails were observed on bedding planes. *Clast-supported sandstone and conglomerate* is composed mostly of reworked volcanic ash with pumice clasts up to 1 ft (0.3 m) in diameter. It is bedded or laminated. Thick (2 to 5 ft (0.6 to 1.5 m)) sets of planar cross beds are common. *Vitric tuff* is a white to cream-colored ash with sparse crystals of biotite, plagioclase, sanidine, and also some accidental lithics. Pumice clasts up to 1 ft (0.3 m) in diameter are common, as is petrified wood. This lithofacies is massive and lacks bedding. *Matrix-supported conglomerate* contains cobbles and pebbles of andesite, welded tuff, orangish-tan chalcedony, quartzite, quartz, and feldspar suspended in a matrix of white volcanic ash. It is weakly lithified. In many places it is recognized by concentrations of cobbles littering the ground. *Limestone* was mapped separately; see below. Generally, the Antero Formation is nonresistant, easily eroded, and is a valley-former that crops out poorly; however, the limestone lithofacies is resistant to erosion and forms small ledges and knobs. Kirkham and others (2012) reported an age of 34.03 ± 0.09 Ma (using a Fish Canyon Tuff (FCT) age of 28.03 Ma) for the vitric tuff lithofacies in the Antero Reservoir quadrangle to the west. Recalibrated to a FCT age of 28.201 Ma, this age is 34.24 Ma. This places deposition of the Antero Formation at the very latest Eocene or earliest Oligocene. On the west side of the Agate Creek fault, the maximum thickness of the Antero Formation in surface outcrops is about 1,100 ft (335 m), and it sits disconformably on the Tallahassee Creek Conglomerate. However, De Voto (1971) reported a subsurface thickness of about 2,000 ft (608 m) along the axis of the Antero syncline. On the east side of the Agate Creek fault, the maximum thickness of the formation is only about 300 ft (91 m), and it sits unconformably on a variety of Proterozoic, Paleozoic, and Cenozoic rocks. It appears to lap onto a pre-existing landscape not unlike that of today. The ash tuff and poorly lithified tuffaceous shale are easily eroded by wind. The matrix-supported conglomerate and limestone lithofacies are prone to rockfall on steep slopes.

₮al **Antero Formation limestone lithofacies** — Micritic to sparry limestone containing ooids, calcareous algae *(Chara)*, snails, ostracods, oncolites, stromatolites, and/or volcanic ash. At many localities the limestone is recrystallized and/or silicified and may also be brecciated. At some localities, it contains agate in a variety of colors from light-gray and white to pinkish-tan. It forms small ridges and mesas. Often it occurs as isolated outcroppings on older bedrock units where clasts of the underlying bedrock may be incorporated into the limestone matrix. Limestone bodies are about 5 to 20 ft (1.5 to 6 m) thick, and commonly massive. Depending on local topographic relief, the unit can be prone to rockfall.

Tallahassee Creek Conglomerate (Eocene)

₮tc **Tallahassee Creek Conglomerate** — Varicolored tuffaceous conglomerate, sandstone, shale, and limestone that is composed mostly of coarse-grained rock fragments and feldspar. Colors include tan, pinkish-tan, reddish-tan, orangish-tan, yellowish-tan, gray, pinkish-brown, and yellowish-orange. Four different facies were observed in the field. *Matrix-supported conglomerate* contains rounded to angular pebbles, cobbles, and boulders of quartz, feldspar, welded tuff, andesite, granite, quartzite, sandstone, chert, and aplite suspended in a matrix of tuffaceous mud, sand, and granules. Boulders are up to 6 ft (1.8 m) in diameter. It lacks sorting or stratification. *Clast-supported sandstone to conglomerate* is medium grained and moderately sorted to conglomeratic and poorly sorted. The sandstones consist mainly of rock fragments, feldspar, and quartz. Some have little matrix, but others are tuffaceous and matrix-rich. Gravel clasts are mostly granule- to pebble-sized. This facies is stratified, and crossbedding is very common. Symmetrical ripples were also observed at one locality. *Tuffaceous shale* is light-gray and laminated to massive. It contains glassy shards, and may contain ostracods or plant debris. *Limestone* was mapped separately; see description below. The tuffaceous shale facies is uncommon, but the sandstone and conglomerate facies are widely distributed over the western half of the quadrangle. They are poorly lithified and crop out poorly. They tend to form valleys and low hills. West of the Agate Creek fault, the Tallahassee Creek Conglomerate is up to 800 ft (244 m) thick, and sits unconformably on Cenozoic and Paleozoic rocks. East of the fault, it is less than 100 ft (30 m) thick, and sits unconformably on Cenozoic, Paleozoic, and Proterozoic rocks. The matrix-supported conglomerate and limestone facies are prone to rockfall on steep slopes.

₮tcl **Tallahassee Creek Conglomerate, limestone facies** — Tan, microcrystalline, recrystallized limestone that may contain fragments of calcareous algae *(Chara)*. Limestones are about 5 to 20 ft (1.5 to 6 m) thick and are commonly massive. They occur only around the westernmost Precambrian uplift.

Volcanic breccia of Buffalo Gulch (Eocene)

₮bb **Volcanic breccia of Buffalo Gulch, main body** — Varicolored volcaniclastic rocks that are predominantly coarse grained and are composed mostly of vitric pyroclasts. The clasts and matrix are rhyolitic in composition. It closely corresponds to the Thirtynine Mile volcanic field laharic breccia of DeVoto (1970), but is assigned the informal name "volcanic breccia of Buffalo Gulch" herein. Five different lithofacies were observed in the field that are mapped as one unit with the exception of local deposits of the tuffaceous sediments described below. *Block and ash deposit* is tan, gray, light- to dark-red, orange, pink, or purple and is the most common lithofacies observed. It can be resistant and caps many of the high mesas and ridges in the east-central part of the map area. Blocks ranging in size from gravel to boulders as large as 5 ft (1.5 m) that are angular pieces of tuff, black vitrophyre, and/or volcanic bombs set in a tuff matrix. Some blocks are flow-banded and some of the larger blocks may have relict cooling joints. The tuff is welded and contains abundant phenocrysts up to 3 mm long of clear to white feldspar with lesser amounts of small biotite and hornblende phenocrysts. The feldspar phenocrysts appear slightly rounded. Occasional flattened pumice clasts may also be present. The matrix is very fine-grained ash that can be dark-gray when fresh but grades to light-tan and white when altered. Weathered surfaces can be rough and blocky where the matrix has weathered out. Whole-rock analysis of four samples of the welded tuff indicates a composition of 70.1 to 73.4% SiO_2, 13.4 to 16% Al_2O_3, 0.9 to 2.7% Fe_2O_3, 0.4 to 2.1% CaO, 0.16 to 0.26% MgO, 1.5 to 3.8% Na_2O, and 4.7 to 6.5% K_2O. Color of the blocks is variable from tan to nearly black. The darker clasts resemble andesite but a handheld XRF analysis showed nearly identical composition. Color may indicate state of devitrification of the matrix. *Matrix-supported conglomerate* is orangish-brown and is the next most common lithofacies observed. Rounded to angular, pebble-to-boulder-sized pieces of welded tuff, vitrophyre, granite, sandstone, and conglomerate are suspended in a matrix of volcanic ash, mud, and sand. *Vitrophyre* is dark orangish-brown, reddish-brown, or purplish-brown with phenocrysts of feldspar and hornblende set in a vesicular matrix of devitrifying glass. *Welded tuff* is pink, white, orange, or brown. It is vitric-crystal tuff with numerous flattened pumice clasts and accidental lithics. Hornblende phenocrysts are common, and secondary quartz is abundant. Deposits of *white, tuffaceous siltstone, sandstone, and pebble conglomerate* are also present as the fifth lithofacies. This lithofacies is commonly found at the base of the unit and is mapped as a separate unit ₮bba where the other lithofacies were not present. It is also found at the top of the unit. Abundant petrified wood can be found in this lithofacies in several locations. Layering is sometimes evident in this unit and can appear convoluted. Rare channel forms are apparent, particularly near the top. Orientation of the channels ranges from N 10° E to N 60° E. The volcanic breccia of Buffalo Gulch has undergone extensive hydrothermal alteration in places and secondary quartz is abundant in many lithofacies. Alteration may result in variable chemical composition. The alteration increases its resistance to erosion, so altered areas form isolated knobs. The unaltered areas form valleys between the knobs. Sanidine in sample A0653b from an outcrop in sec. 21, T. 13 S., R. 75 W. yielded an $^{40}Ar/^{39}Ar$ single-crystal fusion age of 34.27 ± 0.05 Ma. Thickness of the unit is variable but may reach 200 ft (61 m) thick. It sits unconformably on a variety of Cenozoic, Paleozoic, and Proterozoic rocks. In areas of high topographic relief the unit can be prone to rockfall.

₮bba **Volcanic breccia of Buffalo Gulch, volcaniclastic lithofacies** — White to tan tuffaceous siltstone, silicified tuff, sandstone, and conglomerate. This is a recessive unit at the base of the volcanic breccia of Buffalo Gulch that is commonly poorly consolidated. The most common rock type is tan to white tuffaceous siltstone. Local beds of white to gray pebble conglomerate containing angular to sub-rounded pieces of chert and welded tuff in a white ashy sand matrix are also present. This conglomerate can be more indurated than the siltstone. Distribution along the Agate Creek paleovalley suggests a southwest to northeast orientation of a possible channel. This lithofacies is up to 50 ft (15 m) thick.

₮am **Middle andesite series (Eocene)** — Gray to brown to purple volcaniclastic rocks and flows that are primarily andesitic in composition. It closely corresponds to the Thirtynine Mile volcanic field andesite flows of DeVoto (1970) and the lower member of the Thirtynine Mile Andesite of Epis and others (1979). It is older than the Tallahassee Creek Conglomerate (PEtc) placing it older that what has been called the Thirtynine Mile Andesite in the past and its stratigraphic assignment is uncertain. The unit tends to be recessive, forming low hills with occasional isolated knobs of more resistant massive andesite that may be erosional remnants of flows. Two lithofacies are observed in the map area. *Massive andesite and brecciated andesite*, typically gray to dark-gray that weathers brown, purple-brown and reddish-brown is more common in the lower part of the unit. The andesite can be aphanitic to porphyritic with small phenocrysts of plagioclase, hornblende, biotite, and rare pyroxene. The brecciated phase consists of clasts of andesite in a similar matrix indicating it is an autobreccia. Whole-rock analysis of a representative sample of the andesite indicates a composition of 56.0% SiO_2, 17.6% Al_2O_3, 6.8% Fe_2O_3, 4.9% CaO, 1.8% MgO, 4.1% Na_2O, and 4.1% K_2O classifying it as a trachyandesite. *Matrix-supported conglomerate* containing angular to subrounded pebbles, cobbles and small boulders in a poorly sorted ash matrix comprises the dominant lithofacies. Composition of the clasts can be variable including dark-gray and gray andesite, reddish-brown andesite, and reddish, vesicular andesite. Sanidine in sample A0105 from an outcrop in sec. 4, T. 13 S., R. 75 W. yielded an $^{40}Ar/^{39}Ar$ single-crystal fusion mini-plateau age of 34.44 ± 0.05 Ma. The unit is as thin as 10 ft (3 m) in the map area but thickens to over 300 ft (91 m) just to the east of the quadrangle near the townsite of Balfour. The variable thickness suggests that it was deposited upon a landscape with topographic relief. Locally, it may be prone to rockfall.

Wall Mountain Tuff (Eocene)

₮wm **Wall Mountain Tuff, welded facies** — Cream-colored to pinkish-tan, densely welded vitric-crystal tuff. The tuff is rhyolitic in composition. Crystals are 1-2 mm in diameter and include clear sanidine, black biotite, chalky-white plagioclase, and rare quartz. In some places a black, glassy, basal vitrophyre is present. The tuff commonly has a eutaxitic texture that can appear as bedding or crossbedding; in other places it appears massive. Locally it is hydrothermally altered and heavily stained by iron oxide and secondary quartz is common. It is resistant to erosion and form ridges and caps mesas. Whole-rock analysis indicates a composition of 71.1% SiO_2, 15.1% Al_2O_3, 0.79% Fe_2O_3, 1.21% CaO, 0.28 % MgO, 2.87% Na_2O, and 6.37% K_2O. A single-crystal total fusion $^{40}Ar/^{39}Ar$ analysis of sanidine from sample A0100 collected from an outcrop in sec. 3, T. 13 S., R. 75 W. indicated an age of 37.07 ± 0.08 Ma for the tuff. The tuff sits unconformably on a variety of Cenozoic, Paleozoic, and Proterozoic rocks and can be as thick as 100 ft (30 m) in some areas or as thin as a few feet in other areas. This unit is prone to rockfall on steep slopes. In the region, the Wall Mountain Tuff is recognized as a source of dimension stone.

₮wma **Wall Mountain Tuff, tuffaceous, non-welded ash lithofacies** — Local deposits of cream-colored to white ash and reworked ash that, in places, lies above and below the welded tuff, and in other places, occurs without the welded tuff. It includes silicified siltstone and thinly laminated mudstone that may contain plant fragments and imprints. It can also include conglomerate beds made up of pumice fragments in an ashy matrix. It is hydrothermally altered and stained with iron oxide. The lithofacies can be up to 40 ft (12 m) in thickness and is found in the west-central part of the map area.

₮cl **Lower boulder conglomerate (Eocene)** — Tan to gray cobbles and boulders of mixed lithology in a coarse-grained sand and pebble matrix beneath the Wall Mountain Tuff. Cobbles and boulders are rounded to subrounded and are up to 2 ft (0.6 m) in diameter. Clast lithologies include gray to cream quartzite; limestone and dolomite; gray, brown and maroon sandstone; andesite and dacite; and granite and gneiss. It closely resembles the conglomerate lithofacies of the Tallahassee Creek Conglomerate but is found directly beneath the Wall Mountain Tuff. In most exposures the conglomerate is found above the Echo Park Alluvium conglomerate lithofacies (₮ec). Clasts are distinctively larger and cleaner than the underlying conglomerate and, therefore, it is mapped as a separate unit. It is not present everywhere and thickness may be up to 40 ft (12 m). In steep exposures it may be prone to rockfall. It also can be a weak layer beneath the Wall Mountain Tuff (₮wm) where initial landslide failure surfaces form.

₮vc **Lower volcaniclastic unit (Eocene)** — Gray to maroon and brown volcaniclastic unit containing four main lithofacies that are mapped as one unit. *Conglomerate*, that is typically gray to brown and occasionally maroon containing pebble-sized, subrounded clasts of gray to tan, biotite-rich welded tuff in a matrix of very fine-grained sand and possible volcanic ash, makes up most of this unit. The matrix may also be deeply stained by iron oxide. There is little evidence of bedding and the clasts are matrix supported. *Quartz sandstone*, that is tan to pink and occasionally deep-red, fine- to medium-grained, and made up of well-rounded to subangular grains of quartz and minor feldspar in a cryptocrystalline matrix, is scattered throughout the conglomerate lithofacies. Typically it is massive but locally is thinly bedded, with planar laminae. Occasionally, the sandstone is penetrated by a network of lighter-colored veins up to several millimeters thick that do not have a particular orientation. In several locations the sandstone is in depositional contact with the conglomerate lithofacies; however, distinct bedforms have not been observed in outcrop. *Mudstone*, that is gray, granular to pebbly with chunks of fossil wood, clasts of matrix-supported volcanic breccia, and clasts of welded tuff, is a less common lithofacies. A localized *andesite* flow that is gray; porphyritic with crystals of plagioclase and quartz; and minor vesicles is exposed just east of CR 53 in sec. 33, T. 12 S., R. 75 W. This unit is separated from older Paleogene and Precambrian rocks by an unconformity, and it may be as thick as 200 ft (60 m). Locally it may be prone to rockfall.

₮ad **Andesitic and dacitic volcanic rocks (Eocene)** — Gray, grayish-purple, grayish-green, and tan volcanic breccia with andesitic to dacitic composition. We tentatively correlate it with andesitic and dacitic volcanic rocks found on the Garo quadrangle (unit Tad of Kirkham and others, 2007). Two lithofacies were observed in the field. *Clast-supported breccia* contains clasts of andesite to dacite in a glassy to cryptocrystalline matrix. Clasts are up to 0.5 ft (15 cm) diameter and are hydrothermally altered. They contain phenocrysts of plagioclase and biotite, as well as secondary quartz. *Matrix-supported breccia* contains clasts of tuff and aphanitic igneous rocks in a muddy, sandy, granular matrix. The andesitic and dacitic rocks occur only in the north-central part of the quadrangle. They are up to 140 ft (42 m) thick, and are separated from the underlying Paleozoic rocks by an angular unconformity. They are prone to rockfall on steep slopes.

Echo Park Alluvium (Eocene)

₮ec **Echo Park Alluvium, conglomerate lithofacies** — Gray to light-gray cobbles and small boulders of mixed lithology in a sandy matrix. Cobbles and boulders are rounded to subrounded up to 0.5 ft (15 cm) in diameter. Clast lithologies include abundant limestone and dolomite; gray to cream quartzite; gray chert; andesite; maroon sandstone; and granite and gneiss. In many locations the cobbles are coated with white $CaCO_3$. It typically occurs above the mudstone and sandstone lithofacies of the Echo Park Alluvium, but locally, it is interbedded with the sandstone lithofacies. The lower boulder conglomerate unit (₮cl) is often found just above this lithofacies. This lithofacies is distinguished from the overlying conglomerate by the smaller clast size, abundant $CaCO_3$ coating, and higher content of carbonate lithologies. Thickness may be up to 30 ft (10 m). It may be prone to rockfall on steep slopes. It also may be a zone of weakness beneath the Wall Mountain Tuff (₮wm) where inital landslide failure surfaces form.

₮em **Echo Park Alluvium, mudstone lithofacies** — Gray, tan and red mudstone interbedded with tan to brown, fine-grained, friable sandstone. The mudstone is typically poorly consolidated to weekly indurated with little to no bedding apparent. It often dries with an irregular "popcorn" texture. Occasionally it contains irregular conchoidal fracturing. Locally it may be dark-gray indicating high organic content. It appears to be interbedded with the Echo Park Alluvium sandstone lithofacies and may be as thick as 400 ft (122 m). This unit may be prone to hydrocompaction, swelling, and rapid erosion.

₮es **Echo Park Alluvium, sandstone lithofacies** — Tan to rusty-brown sandstone and pebble conglomerate containing interbeds of mudstone. The sandstone is typically medium to coarse grained, moderately indurated, and weakly reactive to hydrochloric acid. Sorting is poor to medium with an arkosic composition containing abundant lithic clasts. The matrix is distinguished from the Antero Formation (₮a) by a lack of white pumice fragments and light-colored matrix. It is typically massive to weakly horizontally laminated with rare low-amplitude ripple crossbeds. Iron oxide staining is common. It may be in depositional contact with older Precambrian and Paleozoic rocks within the Hartsel uplift where the grain size is often larger. Cobbles can include Precambrian and Paleozoic clasts depending on location. A detrital zircon analysis of sample A0384 collected from this unit in sec. 20, T. 12 S., R. 75 W. yielded a distribution of 92% of crystals between 62 and 79 Ma (M. Schmitz, Boise State University, written communication, 2017) and one crystal with the youngest age of 52 ± 5 Ma. It is stratigraphically beneath the Wall Mountain Tuff (~37 Ma), which places this unit as lower to middle Eocene. The unit is up to 200 ft (60 m) thick and is separated from the underlying Precambrian and Paleozoic rocks by an angular unconformity. On steep slopes the indurated sandstone may be prone to rockfall.

₮e **Echo Park Alluvium, undivided** — Shown in cross section only

KPu **Cretaceous to Permian, undivided** — Shown in cross section only

Upper Minturn and lower Maroon formations, undivided (Middle Pennsylvanian to Permian)

PPmm **Upper Minturn and Lower Maroon formations, undivided** — Red, pink, tan, and gray sandstone, siltstone, shale, conglomerate, dolomite, and limestone. The sandstones and siltstones are fine to coarse grained. They are arkosic, with abundant pink feldspar. The fine-grained lithologies commonly are laminated or ripple cross-laminated. The coarser lithologies are bedded, trough crossbedded, or planar crossbedded. The conglomerates contain granules, pebbles, and cobbles of quartz, feldspar, granitic rocks, sandstone, and limestone up to 10 inches (25 cm) in diameter, set in a matrix of coarse feldspathic sand. The limestones and dolomites were mapped separately; see descriptions below. East of the Agate Creek fault, and north of the Poyner Ranch fault, unit PPmm sits nonconformably on Proterozoic rocks, as described below. It is as much as 180 ft (55 m) thick. West of the quadrangle boundary on the adjoining Antero Reservoir quadrangle, approximately 3,800 ft (1,155 m) of Paleozoic rocks are present between the top of the Proterozoic rocks and the base of the upper Minturn Formation (Kirkham and others, 2012). DeVoto (1971) reported collecting middle Desmoinesian foraminifera from the basal 10 ft (3 m) of the outcrop in SW ¼ SW ¼ sec. 30, T. 12 S., R. 75 W. North of the Hartsel fault, the upper Minturn Formation is about 2,000 ft (610 m) thick, and sits conformably on the evaporite facies. The lower Maroon Formation is at least 2,400 ft (730 m) thick. The carbonates are prone to rockfall on steep slopes.

PPmmc **Upper Minturn and lower Maroon formations, unnamed limestone and dolomite beds** — Light-gray, finely crystalline limestone and tan, finely crystalline dolomite, occurring in beds about 2 to 10 ft (0.6 to 3 m) thick, or in mounds as much as 100 ft (30 m) thick. Contains crinoids, rugose corals, brachiopods, bryozoa, gastropods, and bivalves, as well as intraclasts and algal laminae. Beds of limestone and dolomite occur in the outcrops near the northern edge of the quadrangle, and dolomite mounds occur around the edges of the westernmost Proterozoic uplift.

Pme **Minturn Formation, evaporite lithofacies** — Light-gray to dark-gray mud shale, gypsiferous mud shale, limestone, gypsum, and fine sandstone. The limestones and sandstones weather to tan. The shales and sandstones are laminated to thinly bedded and the sandstones are arkosic. The limestones are micritic or stromatolitic and contain ooids and intraclasts. Some of the limestones are vuggy and tufa-like. The gypsum is very coarsely crystalline. In some places it has a nodular texture with stringers of other minerals separating nodules, often referred to as "chicken wire" structure; in other places, relict laminae are present. The evaporite lithofacies is a valley-former; it tends to form cryptogamic soils and sinkholes. Its total thickness is unknown, but at least 1,950 ft (595 m) are present on the Hartsel quadrangle to the north. The Minturn Formation evaporite lithofacies can form corrosive soils and swelling soils. Dissolution of evaporites can form karst features, and can cause collapse.

Pmc **Minturn Formation, Coffman Member** — Shown in cross section only

Pml **Minturn Formation, lower member** — Shown in cross section only

Pb **Belden Formation** — Shown in cross section only

MDO€u **Mississippian through Cambrian, undivided** — Shown in cross section only

INTRUSIVE IGNEOUS AND METAMORHPIC ROCKS

YX?pa **Aplite and pegmatite (Mesoproterozoic-Paleoproterozoic?)** — Aplite is light- to dark-pink, finely crystalline alkali granite with pink crystals of potassium feldspar and light-gray crystals of quartz. Pegmatite is white to pink, very coarse-grained alkali granite with white crystals of milky quartz and pink crystals of potassium feldspar. Muscovite and biotite may be present in varying amounts. The aplite and pegmatite occur as small dikes, about 10 ft (3 m) wide and a few hundred ft (50 to 100 m) long. They tend to occur together. Only the longer, more continuous dikes are shown on the map. The aplite also occurs in bodies that may reach 500 ft (152 m) in width. The aplite and pegmatite are typically more resistant to erosion than the surrounding host rock and form ridges and knobs in the Proterozoic rocks on the quadrangle.

Xmi **Mafic dikes (Paleoproterozoic)** — Dark-gray to black bands of aphanitic mafic rock up to 20 ft (6 m) in width that are typically vertical to subvertical within the host granite. Some bodies contain small phenocrysts of plagioclase, biotite, and hornblende. Occasionally the dikes may be strongly foliated and occur adjacent to foliated shear zones in the host rock (YXc). The mafic dikes are typically less resistant to erosion than the surrounding host rock.

Xgp **Granite-quartz monzonite porphyry (Paleoproterozoic?)** — Gray to pinkish-gray, coarse-grained plutonic rock containing pink potassium feldspar, gray quartz, white plagioclase feldspar, black biotite, magnetite, and rare muscovite. Quartz content is approximately 20% and classification of the rock as granite or quartz monzonite can be arbitrary in the field. The quartz and plagioclase crystals can be up to 0.5 inches (1.3 cm) in diameter and the biotite tends to be finer grained, occuring abundantly in patches throughout the rock. The pink potassium feldspar often occurs as large pheonocrysts, or intergrowths containing other minerals, up to 2 inches (5 cm) in diameter in a groundmass that is massive to very weakly foliated. The phenocrysts give the rock a porphyritic texture with weathered surfaces having a characteristic knobby texture. This rock intrudes the pink granite (Xg) along the Agate Creek paleovalley. It is the most common plutonic rock in the Proterozoic uplifts on the quadrangle where it is typically resistant to erosion, but somewhat less so than granite (Xg). Spheroidal weathering rinds and exfoliation textures are common, and locally, it may weather to grus. Where deeply weathered, it contrasts with cross-cutting pegmatite and aplite bodies and nearby granite bodies. This unit is prone to rockfall on steep slopes.

Xgf **Foliated granite (Paleoproterozoic?)** — Gray to pink-gray, equigranular granite that is moderately to strongly foliated. It is typically fine grained with crystals of white to gray plagioclase, pink potassium feldspar, quartz, and abundant biotite. Crystal sizes range from 1/16 to 3/16 inches (2 to 5 mm). Foliation is widespread throughout the unit in contrast to the foliated shear zones found in the granite (Xg) and gray granite-quartz monzonite (Xgp). It is found in the southern part of the map area where it weathers into rounded outcrops or fins where strongly foliated. The unit is prone to rockfall on steep slopes.

Xg **Granite and alkali feldspar granite, undivided (Paleoproterozoic)** — Granite is pinkish-gray to reddish-gray and medium crystalline to coarsely crystalline. It contains pink potassium feldspar, gray quartz, white plagioclase feldspar, and black biotite in crystal sizes from 0.4 to 0.8 in (1 to 2 cm). In some places, weak gneissic banding is present. Alkali feldspar granite is reddish-pink and coarsely crystalline. It contains dark-pink to dark-red potassium feldspar and gray quartz. It is conspicuously lacking in plagioclase feldspar and mafic minerals. Bodies of granite and alkali feldspar granite occur together in close proximity, so they were mapped together as one unit. They are resistant to erosion and are common in the Proterozoic uplifts on the quadrangle. The rocks are prone to rockfall on steep slopes.

Xmx **Mafic inclusions (Paleoproterozic)** — Dark-gray inclusions, or xenoliths, in the granitic host rocks that are medium to coarsely crystalline, and massive to moderately foliated. Mineral content is plagioclase, pyroxene, hornblende, and minor biotite. The rocks are prone to rockfall on steep slopes.

YXu **Igneous and metamorphic rocks, undivided (Paleoproterozic)** — Shown in cross section only

TECTONITE ROCKS

₮X?fb **Fault breccia and fault gouge (Paleogene to Paleoproterozoic?)** — Variably colored breccia (depending on host rock), containing rounded to angular clasts of the host rock. Most clasts are between 1/6 and 5/8 (2 mm and 15 mm) in diameter but can be as large as 6 in (30 cm). Locally the breccia may be hydrothermally altered, stained with iron oxide, or contain voids lined with drusy quartz. Fault gouge is black. It contains clasts of granite and aplite having the same size and shape as those in the fault breccia, but the clasts are suspended in a black, microcrystalline matrix. The matrix has tiny pyrite crystals less than 1 mm in diameter embedded in it. Fault breccia and fault gouge occur in shear zones that cross-cut the Proterozoic rocks on the quadrangle. The shear zones are up to 70 ft (21 m) wide. Typically, they are less resistant than the surrounding granitic rocks, and tend to form linear valleys. The Thirtyone Mile-Buffalo Gulch fault zone separates Paleoproterozoic granite to the northeast from Paleogene volcanic and volcaniclastic rocks to the southwest. Along this fault in sections 29 and 33, T. 12 S., R. 75 W. the granite (Xg) is brecciated and slightly more resistant to erosion than the undeformed granite above it forming a series of small ridges at the base of the slope. Several prominent fault planes with well-defined slickenlines are also exposed in this area.

YXf **Foliated shear zones (Mesoproterozoic-Paleoproterozoic?)** — Linear bands of foliation within an otherwise massive plutonic body. Mineral composition is the same as the surrounding host rock but in the zone it is weakly to highly foliated in contrast to the surrounding rock. Typical width is up to 10 ft (3 m) and linear extent is often difficult to determine because of surficial deposits. Projections on the map are based on scattered float.

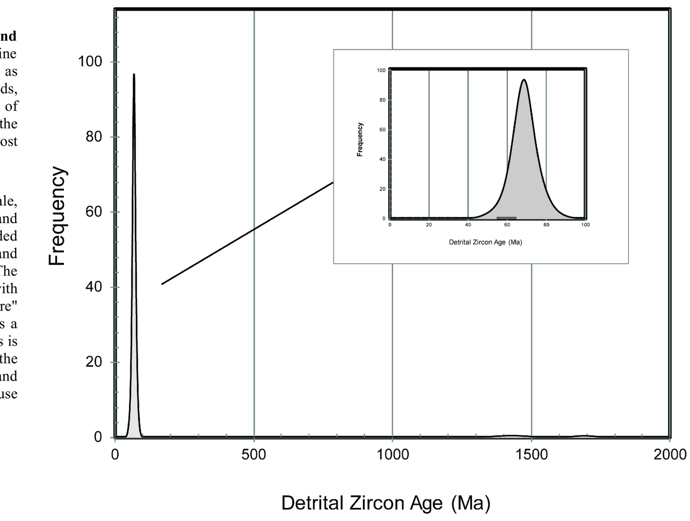
YXc **Cataclasite bodies (Mesoproterozoic-Paleoproterozoic?)** — Linear bands of light-gray to pink, fine-grained to cryptocrystalline rock that is weakly to strongly foliated. Composition is quartz, feldspar, and muscovite in varying quantities. Quartz is the most common mineral grain and the grains typically have undulose extinction in thin section. The rock may be mistaken for metasedimentary quartzite when found scattered in float. The bodies occur as linear bands up to three feet (0.9 m) with linear extent difficult to determine because of surficial cover. Projections on the map are based on scattered float.

Table 1. Summary of geochronology analyses in the Antero Reservoir NE quadrangle

Sample ID	Formation	Type	By	Age (Ma)
A0100	₮wm	$^{40}Ar/^{39}Ar$, sanidine [1]	OSU Argon Geochronology Laboratory	37.07 ± 0.08
A0105	₮am	$^{40}Ar/^{39}Ar$, sanidine [1]	OSU Argon Geochronology Laboratory	34.44 ± 0.05
A0384	₮es	Detrital zircon [2]	Boise State University	<52 ± 2
A0653b	₮bb	$^{40}Ar/^{39}Ar$, sanidine [1]	OSU Argon Geochronology Laboratory	34.27 ± 0.05

1) Calibrated to a Fish Canyon Tuff age of 28.201 Ma ± 0.023 Ma.
2) Detrital zircon distribution is shown in Figure 1.

Figure 1: Detrital zircon age distribution plot for sample A0384 of the Echo Park Alluvium sandstone facies.



MAP SYMBOLS

Contact — Approximately located

Fault — Dashed where approximately located, queried where inferred, dotted where concealed; U = upthrown side, D = downthrown side where known

Normal fault — Dashed where approximately located, queried where inferred, dotted where concealed; ball and bar on downthrown block

Reverse fault — Dashed where approximately located, dotted where concealed; rectangles on upthrown block

Anticline — Dashed where approximately located, dotted where concealed, arrow shows direction of plunge

Syncline — Dashed where approximately located, dotted where concealed, arrow shows direction of plunge

Landslide scarp — Hachures point down scarp

A A′ **Alignment of cross section**

Strike and dip of inclined bedding — Showing direction and angle of dip in degrees from field measurement

Strike and dip of inclined bedding — Showing direction and angle of dip in degrees as estimated from aerial photographs or DEM

Horizontal bedding

Strike and dip of foliation — Showing direction and angle of dip in degrees

Horizontal foliation

Vertical foliation

Strike and dip of fault — Showing direction and angle of dip in degrees

Vertical fault

Estimated azimuth of slickensides — Showing angle of plunge

₮bb **Location of isolated bedrock outcrop**

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