COLORADO GEOLOGICAL SURVEY
COLORADO SCHOOL OF MINES
GOLDEN, COLORADO

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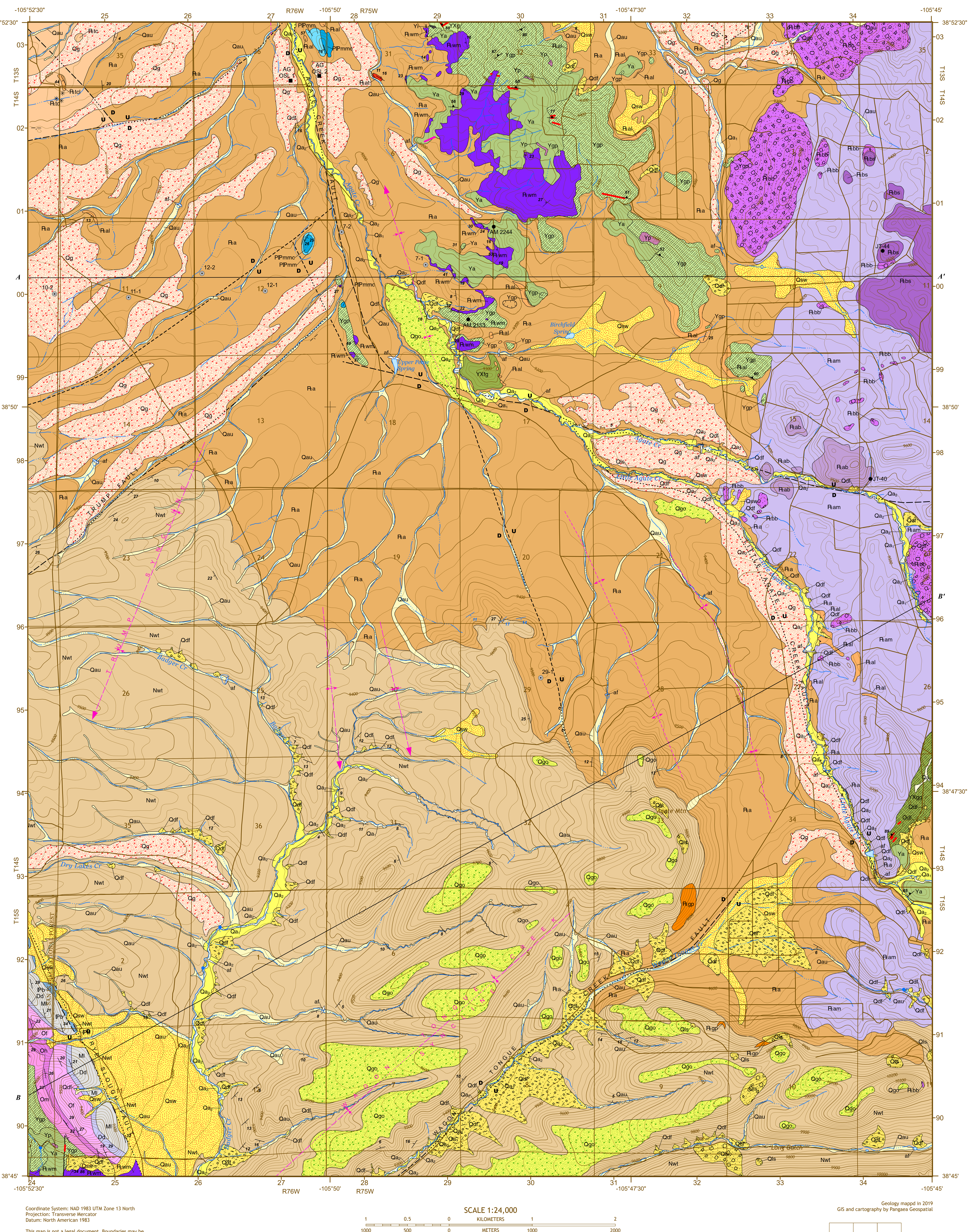

Coordinate System: NAD 1983 UTM Zone 13 North
Projection: Transverse Mercator
Datum: North American 1983

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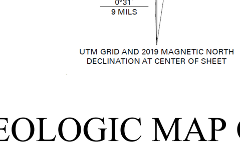
Roads..U.S. Census Bureau, 2016
Roads within US Forest Service Lands......................FSTopo
Data with limited Forest Service updates, 2013
Names...GNIS, 1978-2017
Contours....................National Elevation Dataset, 2002-2005
Boundaries.....Multiple sources; see metadata file 2017-2018
Public Land Survey System.................................BLM, 2018



SCALE 1:24,000

KILOMETERS: 1 0.5 0 1 2
METERS: 1000 500 0 1000 2000
MILES: 1 0.5 0 1
FEET: 1000 500 0 1000 2000 3000 4000 5000 6000 7000 8000 9000 10000

CONTOUR INTERVAL 20 FEET

QUADRANGLE LOCATION

Geology mappd in 2019
GIS and cartography by Pangaea Geospatial

Antero Reservoir	Antero Reservoir NE	Guffey NW
Castle Rock Gulch	Agate Mountain	Dicks Peak
Cameron Mountain	Gribbles Park	Black Mountain

ADJOINING QUADRANGLES

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GEOLOGIC MAP OF THE AGATE MOUNTAIN QUADRANGLE, PARK COUNTY, COLORADO

By Karen J. Houck, Jay Temple, Kassandra O. Lindsey, Lauren D. Broes, and Daniel P. Miggins
2024

DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSITS

Colors are designated according to the Munsell soil color charts (Munsell Color Company, 1991). Description of soil-carbonate morphology is after Machette (1985) and Birkeland (1999).

HUMAN-MADE DEPOSITS

af — **Artificial fill (Uppermost Holocene)** — Artificial fill includes riprap, fill, and refuse placed during construction of roads, railroads, buildings, dams, and landfills. The unit generally consists of clay, silt, sand, and rock fragments. Extensive areas of artificial fill may exist in residential and commercial developments in the map area; however, some fill deposits are typically less than 1.5 m thick and may be difficult to delineate. Fill materials can vary in particle size and may locally include refuse of many types including household and industrial waste. Artificial fill may be subject to settlement, slumping, and erosion if not adequately compacted or emplaced. The unit is as much as 6 m thick.

ALLUVIAL DEPOSITS

Qa_1 — **Alluvium one (Upper to Middle Holocene)** — Olive brown to dark olive-brown (2.5Y 4/3 to 2.5Y 3/3) silt, fine sand, and gravel. Sand particles are predominantly quartz with lesser amounts of feldspar and opaque minerals. Deposits are unstratified to weakly stratified. Gravel lenses and dispersed gravels are present locally; gravel lenses are up to 5 cm thick. Clasts in gravel lenses are <2.5 cm in diameter. No visible secondary carbonate nodules were observed but the matrix does effervesce locally in response to dilute hydrochloric acid. In the northern part of the mapped area, a basal, matrix supported, weakly stratified gravel bed is locally exposed. In this area, the uppermost silt to fine sand is about 1 m thick. The gravel clasts are subangular to subround, and up to a 6 cm diameter. The unit underlies the most recently active channels of Agate, Little Agate, Badger, and Wagon Tongue creeks. It is hydraulically connected to streams, and groundwater is typically very close to the surface. The unit may be a source of sand and gravel. Areas mapped as unit Qa_1 may be prone to flooding and collapse. Thickness may be as much as 5 m.

Qa_2 — **Alluvium two (Middle to Lower Holocene)** — Poorly to moderately stratified, silt to fine sand. Sand particles are predominantly quartz with lesser amounts of feldspars and opaque minerals. Soil development includes an uppermost A horizon and weakly developed B and Bk horizons. The A horizon is approximately 30 to 36 cm thick and is olive-gray (5Y 4/2). The B horizon is an approximately 46 cm-thick, with weak prismatic structure that is dark olive-gray (5Y 3/2). The lowermost soil unit is a Bk horizon with Stage I+ to II carbonate development that contains few to common nodules and is very dark grayish brown (2.5Y 3/2). The unit underlies areas directly adjacent to unit Qa_1 along Agate, Little Agate, Badger, and Wagon Tongue creeks. Terrace surfaces underlain by unit Qa_2 are 1 to 1.5 m above adjacent modern channels. The unit is a potential source of sand and gravel. Areas underlain by unit Qa_2 may be prone to flooding and collapse. The unit is likely as much as 2 m thick.

Qau — **Alluvium, undivided (Holocene and Upper Pleistocene)** — Deposits are unstratified to moderately stratified, silty sand to matrix supported, poorly sorted gravel. Gravel clasts are angular to subangular and reach up to 13 cm in diameter. Color and composition of clasts are dependent on source material and therefore vary across the quadrangle. In general, colors are typically pale brown (10YR 6/3) to dark yellowish-brown (10YR 4/4). Unit Qau underlies unnamed ephemeral streams. Sediments are usually deposited during high-energy, high-volume storm events (Barkmann and others, 2018). The unit may be correlative with units Qai, Qaio, and Qac of Barkmann and others (2018) and unit Qac of Wallace and Keller (2003). The unit may transmit limited groundwater. Areas underlain by unit Qau may be prone to flooding, collapse, and/or debris flow. Estimated thickness locally exceeds 1.5 m or greater (Barkmann and others, 2018).

Qg — **Gravel (Holocene and Upper Pleistocene)** — Poorly sorted silt to gravel. Composition of clasts and color of deposits vary by location within the mapped area, largely due to differences in source area geology. Exposures are rare and outcrops were not observed. There are multiple terrace levels throughout the mapped area. Generally, the lower terrace surfaces are 2 to 12 m above adjacent modern stream channels and higher terrace surfaces are 5 to 20 m above adjacent modern stream channels.

Terraces underlain by unit Qg extending from Kaufman Ridge on the west side of the mapped area are typically capped by clasts of metamorphic rocks, granitic rocks, vein quartz, and clasts derived from the Antero Formation that are 3 to 6 cm in diameter. Clasts are angular to subround. Carbonate rind thickness is 2 mm or less; some clasts may be reworked from older deposits. The topmost 0.3 m of the unit may locally include reworked silt to medium sand of possible eolian origin. Two terrace levels were identified. The lower gravel-capped surfaces are approximately 6 to 10 m above ephemeral streams while upper surfaces are 15 to 20 m above ephemeral streams. The unit is less than 7 m thick.

Terraces underlain by unit Qg in the northeastern part of the mapped area are capped by brown to black andesitic clasts, and red, gray, and brown volcanic breccia clasts that are up to 15 cm in diameter. Clasts are subangular to subround. The matrix is composed of silt to medium sand. Discontinuous to continuous carbonate rinds are present on clasts and are up to 1 mm thick. Some of these clasts may have been reworked from older deposits. Surfaces are approximately 4 to 5 m above modern ephemeral streams. The unit is up to 2 m thick.

Two soil pits were hand excavated within the mapped area: Site AG 1 located at SW ¼ SE ¼ sec. 36, T 13 S, R 76 W to a depth of 107 cm and Site AG 2 at SE ¼ SE ¼ sec. 36, T. 13 S., R. 76 W to a depth of 97 cm. The deposit at AG 1 is predominantly unstratified to well stratified, clast-supported pebble gravel. Clasts are subround to round, varying in color from red, light-grey, dark-grey, and black. They may reach up to 3 cm in diameter and are andesitic and basaltic in composition. From 0 to 84 cm depth, the unit is clay to medium sand. Coarser sand lenses are up to 2 to 3 cm thick. From 84 to 107 cm below ground surface, sand content increases and grains are coarser. Below 84 cm, the unit is silt to medium sand, with coarse sand and pebble gravel lenses up to 5 cm thick. The following description was provided by Laura Craven, Natural Resource Conservation Service (personal commun., 2019) : A horizon, 0 to 20 cm, brown (10YR 4/3) gravelly loamy sand, noneffervescent; Bw1 horizon, 20 to 36 cm, brown (10YR 4/3) very gravelly loamy sand, weak fine subangular structure, noneffervescent; Bw2 horizon, 36 to 65 cm, yellowish-brown (10YR 5/5) very gravelly sand, weak fine subangular blocky structure, noneffervescent; Bk1 horizon, 65 to 83 cm, yellowish-brown (10YR 5/6) very gravelly sand, weak medium subangular blocky structure, 2 percent fine carbonate masses, slight effervescence; Bk2 horizon, 83 to 87 cm, yellowish brown (10YR 5/6) gravelly sandy loam, weak medium blocky structure, 30 percent coarse carbonate masses, violent effervescence; C horizon, 87-100 cm, yellowish-brown (10YR 5/4) very gravelly sand, single grain structure, noneffervescent.

The deposit at AG 2 is capped by approximately 25 cm of homogenous, stiff, silt to fine sand. This section is similar in texture and appearance to eolian deposits. Beneath is approximately 22 cm of clast supported pebble gravel. Clast lithology is predominantly andesitic with lesser amounts of chert. Clasts are subround to round and up to 4 to 5 cm in diameter. From 48 to 83 cm below ground surface, a Stage II+ to III Bk horizon is present. Carbonate rinds on clasts are continuous and less than 1 mm in thickness. Gravel clasts coarsen with increasing depth below ground, up to 10 cm in diameter. From 83 to 97 cm below ground surface, the unit consists of silt to medium sand. The following description was provided by Laura Craven and Sara Mack, Natural Resource Conservation Service (personal commun., 2019): A horizon, 0 to 10 cm, brown (10YR 5/3) sandy loam, weak fine granular structure, very slight effervescence; Bt1 horizon, 10 to 34 cm, yellowish-brown (10YR 5/4) sandy clay loam, moderate fine prismatic structure, noneffervescent; Bt2 horizon, yellowish-brown (10YR 5/4) sandy clay loam, weak fine subangular blocky structure, noneffervescent; Bk horizon, 50 to 78 cm, brown (10YR 5/2), very gravelly coarse sandy loam, weak medium subangular blocky structure, 50 percent extremely coarse irregular carbonate masses, strong effervescence; C horizon, 78 to 100 cm, grayish-brown (10YR 5/2), very gravelly sand, single grain structure, strong effervescence.

Two samples were collected at AG 1 and AG 2 for optically stimulated luminescence dating. The first sample, AG 1, was taken at an elevation of approximately 2789 m at a depth of 97 cm in fine to medium sand; AG 2 was taken at approximately 2792 m at a depth of 97 cm in medium to coarse sand. Age estimates of 11,395 ± 1,230 at AG 1 and 8,595 ± 840 at AG 2 indicate both sampled deposits are Early Holocene in age.

Unit Qg may be correlative to unit Qgo by Barkmann and others (2018). Segments of the unit are mapped as terraces of differing ages by various authors. Stark and others (1949) mapped part of the unit as "Como Surface", which they inferred to be Pre-Illinoian in age (greater than 200 ka). De Voto (1971) identified parts of the surface as "Terrace A", which he inferred to be Holocene, and "Terrace B", which he inferred to be Wisconsin (80 to 11 ka). All previous age interpretations were made based on the basis of heights above stream level and degree of soil development. Landslides and debris flow initiation are possible at or near the unit's contact with underlying, weaker bedrock units. The unit is a potential source of gravel.

Qgo — **Old gravel (Lower Pleistocene to Upper Pliocene)** — Poorly sorted gravel, sand, silt, and clay. Gravel occurs as a mantle over bedrock. Cobbles and boulders are composed of andesite and basalt that are very similar in composition to clasts from units ₱am and ₱bs. Clasts are up to 2 m in diameter, and are angular to rounded. They occur in a matrix of tan sand, silt, clay, and pebbles of andesite and basalt. The cobbles and boulders have weathering rinds 0.5 to 5 cm thick. They are partially to entirely covered by carbonate and are typically <2 mm thick but can be up to 1 cm thick. Deposits that are higher in the landscape have thicker carbonate rinds and thus are likely older than deposits lower in the landscape. Gravel-capped surfaces underlain by the unit range between 40 and 166 m above modern channels as measured using lidar imagery. Multiple terrace surface heights and different degrees of carbonate rind development likely indicate there was more than one period of deposition of the unit during the Pleistocene. The terrace levels and relationships are complex within the mapped area and it is difficult to identify which major drainage individual terraces are associated with or if they were deposited by previously existing fluvial systems. Therefore, the terraces are mapped as the same unit. The unit was mapped as the "Badger Creek pediment" by De Voto (1971) and the "Badger Creek surface" by Stark and others (1949). On the basis of height above modern stream channels, Stark and others (1949) assigned the unit an age of late Pliocene. Scott (1965) assigned it an age of Early Pleistocene on the basis of its relationship with lower terraces along Badger Creek. The unit is likely not a good source of sand and gravel due to weathering of clasts. Rockfall is a hazard on steep slopes. Unit thickness is approximately 2 to 11 m.

ALLUVIAL AND MASS-WASTING DEPOSITS

Qsw — **Sheetwash and debris-flow deposits, undivided (Holocene to Upper Pleistocene)** — The unit consists of sheetwash and debris-flow deposits that grade into each other laterally, but are not geomorphically distinct or aerially large enough to map as individual deposits. Generally, the unit is poorly to weakly stratified and poorly sorted. An exposure in sec. 3, T. 15 S., R. 75 W. consists of angular to subangular clasts up to 20 cm in diameter, with some clasts exceeding 30 cm. Soil development ranges across the quadrangle, from weakly developed Bt and non-existent Bk horizons, to as much as Stage II to II+ carbonate development in the Bk soil horizon. At this exposure, carbonate rinds are continuous and can be up to 2 mm thick. Throughout the mapped area, sheetwash deposits are generally composed of matrix supported gravel deposits with angular clasts. Where debris-flow deposits are interbedded with sheetwash alluvium, bedrock clasts are as much as 3 cm in diameter. Color and composition of the unit varies depending on source area material but color may vary between light yellowish-brown (2.5Y 6/3) and yellowish-brown (10YR 5/4). Areas underlain by unit Qsw may be prone to flooding, collapse, and/or debris flow. The unit is typically up to 1 m thick but may be thicker locally.

Qdf — **Debris flow deposits (Holocene to Lower Pleistocene)** — Poorly sorted, matrix- to clast-supported gravel. The matrix is commonly mud to medium sand. Clasts are typically angular to subangular and derived from local bedrock units. Clasts can exceed 0.3 m in diameter. Some debris flow deposits along Wagon Tongue Creek have a well-developed Bk horizon that is approximately 0.3 m thick with Stage III carbonate development. Clasts have continuous carbonate rinds, which can exceed 1 mm in thickness. The Bk horizon may be thicker locally. Younger deposits have less developed soils and carbonate rinds that are thinner or not present. Debris flow deposits may be interbedded with alluvial deposits throughout the mapped area. Areas underlain by debris flow deposits may be prone to future debris-flow events, flooding, and/or collapse. Thickness is estimated to be about 7.5 m.

MASS-WASTING DEPOSITS

Qls — **Landslide deposits (Holocene to Upper Pleistocene)** — Unit is composed of unsorted gravel clasts, bedrock fragments, and soil clods. All deposits are mapped in the southeast corner of the quadrangle. Landslides occur at or near the contact of unit Qgo and the underlying, soft Wagontongue and Antero formations. Deposits were identified and mapped on the basis of hummocky topography typical of landslide deposit morphology. Many deposits were obscured by aspen groves. In these locations, lidar was used to map their extent. This unit is not well exposed in the mapped area. Landslides are predominantly translational and rotational. Landslide deposits and areas with similar bedrock units may be prone to future slope failures. Deposits may be up to 6 m thick.

BEDROCK GEOLOGY

Bedrock unit classifications follow those of Carpenter and others (2016). Chemical classification of igneous rocks is that of Le Bas and others (1986) and Frost and others (2001, 2008, 2011). Geologic terms follow the definitions of Neuendorf and others (2005).

Nwt — **Wagontongue Formation (Miocene)** — Light gray, tan, and light brown interbedded conglomerate, sandstone, and mudstone that is cemented with calcite and silica. Two lithofacies are common. *Clast-supported conglomerate and conglomeratic sandstone* contains granules, pebbles, cobbles, and sand in a matrix of white, microcrystalline calcite, causing the rock to resemble concrete. Clasts are rounded to subangular. Beds are 15 to 60 cm thick. Some trough cross-bedding is present. *Matrix-supported conglomerate, conglomeratic sandstone and conglomeratic mudstone* is massive with granule- to boulder-sized gravel suspended in a matrix of sand and/or mud. Gravel clasts are rounded to angular. These massive deposits are up to 3 m thick. Where well-exposed, this facies has root traces and carbonate-rich layers indicative of soil development. West of Badger Creek, the gravel clasts in the Wagontongue Formation consist mainly of K-feldspar, limestone, quartz sandstone, vein quartz, chert, vitrophyre, gneiss, and a distinctive light bluish gray siliceous tuff. Near Badger Creek, clasts of andesite and basalt are also common. East of Badger Creek, the proportion of basalt and andesite clasts increases in the eastward direction while the proportion of other lithologies decreases. Much of the formation is poorly lithified and poorly exposed. It weathers to gently sloping hills in the southern half of the quadrangle. The two best outcrops are on the northeast ends of ridges in sec. 31 and 32, T. 14 S., R. 75 W. DeVoto (1971) reported the occurrence of fossil mammals of early Miocene age (Burdigalian Age, approximately 16 to 20 Ma) in the formation. An angular unconformity separates the Wagontongue Formation from the underlying Antero Formation and Gribbles Park Tuff. It is prone to producing debris flows and landslides, and rockfall is a hazard on slopes greater than 30 degrees. A complete section of the formation is not exposed on the quadrangle, but it is at least 120 m thick.

₱gp — **Gribbles Park Tuff (Oligocene)** — Light-gray to gray to pinkish-gray, fine-grained rhyolitic welded tuff. Sanidine, plagioclase, biotite and dark gray to brown lithic fragments are locally visible. The tuff is exposed along the road in sec. 10, T. 15 S., R. 75 W., sparsely in the northeast part of adjoining sec. 9, and more extensively along the southeast part of Agate Mountain in sec. 4, T. 15 S., R. 75 W. Samples of the Gribbles Park Tuff from the upper Arkansas River Valley yielded $^{40}Ar/^{39}Ar$ sanidine ages of 32.98 +/- 0.14 Ma and 32.91 +/- 0.11 Ma (McIntosh and Chapin, 2004). These authors correlated the Gribbles Park Tuff with the upper Bonanza Tuff, and determined its source to be the Bonanza caldera. The tuff unconformably overlies the Antero Formation. Rockfall is a hazard on slopes greater than 30 degrees. The tuff is approximately 30 m in thickness.

₱a — **Antero Formation (Oligocene)** — The Antero Formation was described in the adjoining Antero Reservoir NE quadrangle (Barkmann and others, 2018) as consisting of five different lithofacies. All five of the facies were observed in the mapped area. Four of these were mapped as one unit and are described here. Two additional lithofacies, limestone and welded tuff, were mapped separately and are described below. The *tuffaceous shale* consists of white to light tan, poorly consolidated, siltstone, mud shale, and clay shale. Laminations are common, and climbing ripples are present. Vitric shards and biotite crystals are present at most localities. The *clast-supported sandstone and conglomerate* is a white to light-gray tuffaceous sandstone to conglomerate with abundant vitric shards, biotite crystals, feldspar crystals, and granule- to pebble-sized pumice clasts. Some outcrops contain andesite pebbles. Bedding is thin to thick, with coarser deposits generally having thicker bedding. Climbing ripples, reactivation surfaces, heavy-mineral layers, and soft sediment deformation occur at some localities. Field-based X-ray fluorescence analysis of the heavy mineral layers yielded 2-3% titanium, 1000-1500 ppm vanadium, and elevated levels of iron. In the southernmost part of sec. 20, T. 14 S., R. 75 W., large-scale cross-beds, approximately 6 m thick, are present. These are interpreted as Gilbert delta deposits. Paleocurrent measurements corrected for tectonic dip yield an average strike of 57 degrees and dip of 30 degrees SE. The *matrix-supported conglomerate* consists of andesite pebbles and cobbles in a matrix of white granular coarse sandstone that is about 80% vitric shards and pumice, and 20% crystals of biotite and feldspar. It occurs as thick beds that are internally massive. The *vitric tuff* is white to light tan and massive, with clasts of tuffaceous siltstone and pumice up to 15 cm in diameter. It is poorly lithified, and is about 4 to 6 m thick. McIntosh and Chapin (2004) reported an $^{40}Ar/^{39}Ar$ average age of 33.76 +/- 0.10 Ma for tuff samples from the Antero Formation. They correlated it with the Badger Creek Tuff, and determined its source to be the Mt. Aetna cauldron. On the west side of the Antelope Creek and Little Agate Creek faults, its contact with the underlying Tallahassee Creek Conglomerate appears to be conformable and gradational. The contact was placed at the base of the lowest occurrence of white vitric ash- and pumice-rich sediment. However, deposits of Tallahassee Creek-like boulders of augen gneiss, granite, Wall Mountain Tuff, and Leadville Limestone up to 1 m in diameter were found interbedded with Antero-like tuffaceous deposits in the lower part of the Antero Formation. On the east side of the Agate Creek and Little Agate Creek faults, the formation unconformably overlies Eocene volcanic rocks and Proterozoic intrusive igneous and metamorphic rocks. Rockfall is a hazard on slopes greater than 30 degrees in the limestone and matrix-supported conglomerate lithofacies. On the west side of the Agate Creek and Little Agate Creek faults, the Antero Formation is up to 264 m thick. On the east side, its maximum thickness is 60 m.

₱al — **Antero Formation limestone facies (Oligocene)** — Tan to light- brown to light-gray micritic limestone to shaley limestone. Shaley limestone is thinly bedded, easily parted, and fissile. Occasional rounded to subrounded quartz detritus, volcanic ash, calcareous algae, small wood fragments, and other lacustrine fossil fragments were observed. In some places, the limestone is oolitic. Limestone beds average 15 to 20 cm in thickness and bedding planes are well-developed. Partial to complete recrystallization and silicification are present. The most common exposures are near the Proterozoic outcrops where the limestone developed in shallow waters proximal to the lakeshore. However, one of the better exposures occurs along Agate Creek in the southeast quarter of sec. 16, T. 14 S., R. 75 W. On slopes greater than 30 degrees, rockfall is a hazard. The thickness in surface outcrops is approximately 3 m or less.

₱at — **Antero Formation welded tuff facies (Oligocene)** — Pinkish-orange, densely welded, vitric tuff. Though numerous quartz-filled voids are present, no phenocrysts and few pumice lapilli were observed. The unit contains two flows, each of which is about 1.2 m thick. The base of each flow has a lag of angular cobbles of silicified limestone. Only one small outcrop of welded tuff was found in sec. 31, T. 13 S., R. 75 W., in the north-central part of the quadrangle. Thickness of the unit is about 2.4 m.

₱tc — **Tallahassee Creek Conglomerate (Eocene)** — Varicolored tuffaceous conglomerate, sandstone, and limestone that is generally tan, yellowish-tan, orangish-tan, or gray. Conglomerate, sandstone, and conglomeratic sandstone occur in beds approximately 1 to 1.5 m thick. Sand is medium- to coarse-grained and contains a mixture of quartz, feldspar, and rock fragments. Gravel clasts include pebbles, cobbles, and boulders of andesite, chert, quartzite, granite, tuff, and vitrophyre. The largest boulders are approximately 1.5 m in diameter. The limestone facies was mapped separately and is described below. The Tallahassee Creek Conglomerate is poorly exposed in an area in the northwest corner of the quadrangle. West of the Agate Creek fault and the Little Agate Creek fault, it unconformably overlies the undivided Minturn and Maroon formations, and possibly the Echo Park Alluvium. East of these faults, it is not present. Falling rocks are a hazard on slopes greater than 30 degrees. The formation is about 30 m thick on the quadrangle.

₱tcl — **Tallahassee Creek Conglomerate, limestone facies** — Light gray, finely crystalline limestone that is extensively silicified in places. The limestone occurs in beds approximately 15-30 cm thick, and contains lacustrine algae *(Chara)*. Sinkholes are associated with the limestone, and rockfall is a hazard on slopes greater than 30 degrees. Thickness is approximately 3 m.

₱atc — **Antero and Tallahassee Creek formations, undifferentiated** — Volcaniclastic sandstone, conglomerate, siltstone, and shale with minor limestone and welded tuff. Thickness is approximately 60 to 300 m. Shown only on cross-section.

₱bs — **Trachybasalt (Eocene)** — Dense, black, fine-grained volcanic rock exposed in the northeastern part of the map area primarily in sec. 11, T 14 S., R. 75 W. Two isolated hills exposed in this area weather along the flanks into talus with flat surfaces that alter to a light-gray to gray to light-brown color. Thin sections contain anhedral to subhedral olivine and augite along with abundant subhedral plagioclase. The plagioclase laths are partially flow aligned and commonly twinned. Whole rock analysis of one sample indicates a composition of 47.7% SiO_2, 15.9% Al_2O_3, 12.4% Fe_2O_3, 8.86% CaO, 5.71% MgO, 3.38% Na_2O, and 2.06% K_2O. This geochemistry plots in the trachybasalt field on the total alkali-silica diagram of LeBas and others, 1986. These results are very similar to results reported by Epis and Chapin (1974) for the upper member of the Thirtynine Mile Andesite, and the trachybasalt on this quadrangle may be correlative with it. The trachybasalt disconformably overlies the breccia of Buffalo Gulch and the middle andesite series. Sample JT44, taken in the NW ¼ sec. 11, T. 14 S., R. 75 W., yielded an $^{40}Ar/^{39}Ar$ date of 34.95+/-0.09 Ma. This date is older than expected, given the stratigraphic position of unit ₱bs. It was collected in an area where hydrothermal alteration is common, so perhaps the sample underwent some minor alteration that affected the results of the dating. Rockfall is a hazard on slopes greater than 30 degrees. The maximum exposed thickness observed in outcrops is about 55 m.

₱bb — **Volcanic breccia of Buffalo Gulch (Eocene)** — Volcanic and volcaniclastic rocks composed of vitric pyroclasts of rhyolite and andesite. Two lithofacies are observed in the Agate Mountain quadrangle and mapped as a single unit. The *block and ash deposit* is the most widespread lithofacies and is a buff to gray, light orange to dark red to purple breccia. It is generally well lithified and forms some of the higher topography in the northeastern portion of the quadrangle. The blocks range in size from gravel to boulders up to 1 m and are composed of angular to subangular fragments of tuff, pumice, and andesite in a welded tuff matrix. This matrix is a fine-grained ash that is dark gray on fresh surfaces and becomes light gray to tan when altered. Phenocrysts of white feldspar and smaller amounts of biotite and hornblende are locally visible in the matrix. A *matrix supported conglomerate* lithofacies was observed in lesser areal extent than the block and ash facies and primarily forms caps on some of the higher knolls in the northeastern portion of the map area. It is an orange to orangish-brown breccia composed of smaller (5 to 15 cm) fragments of tuff, vitrophyre, and granite in a matrix of volcanic ash, mud, and fine-grained sand. The volcanic breccia of Buffalo Gulch was informally named and described on the Antero Reservoir NE quadrangle (Barkmann and others, 2018). Sanidine from a sample collected there yielded an $^{40}Ar/^{39}Ar$ single-crystal fusion age of 34.27 +/- 0.05 Ma (Barkmann and others, 2018). The unit disconformably overlies the middle andesite series. Rockfall is a hazard on slopes greater than 30 degrees. The maximum thickness exposed in outcrops is about 115 m.

₱ab — **Autoclastic volcanic breccia (Eocene)** — Light to medium-gray clast supported volcanic breccia. Fragments are angular, up to 50 cm in size, typically elongated, and randomly oriented. Clasts are distinctly exposed out of a softer, fine-grained matrix of similar composition. The breccia is well exposed in the southern half of sec. 15, T. 14 S., R. 75 W., where a 50 m wall abruptly rises on the north side of Agate Creek. Whole-rock analysis of a sample collected from the east side of this outcrop indicates a composition of 62.4% SiO_2, 14.7% Al_2O_3, 2.82% Fe_2O_3, 6.32% CaO, 0.43% MgO, 3.87% Na_2O, and 4.55% K_2O. This plots in the trachydacite field on the total alkali-silica diagram of LeBas and others (1986). However, the unit is highly altered, so this may not be its original composition. We interpret the unit to be a probable autoclastic volcanic breccia after Fisher (1960) where it is defined as broken fragments of semisolid and/or solid lava formed during confinement beneath the surface or by relatively slow movement of unconfined lava flows. The autoclastic volcanic breccia overlies the middle andesite series with apparent conformity. Sample JT40, taken in the SW ¼ sec. 14, T. 14 S., R. 75 W., yielded an $^{40}Ar/^{39}Ar$ date of 34.55+/-0.08 Ma. The breccia is prone to rockfall on slopes greater than 30 degrees. The maximum exposed thickness is about 60 m.

₱am — **Middle andesite series (Eocene)** — Gray to brown to reddish-brown volcanic rocks primarily of andesitic composition. Two lithofacies were observed in the map area. *Massive andesite and brecciated andesite* is typically gray to dark-gray aphanitic andesite that weathers to a brown to reddish brown and forms low-lying hills in the eastern part of the quadrangle. It can be porphyritic with phenocrysts of plagioclase, hornblende, and biotite. The brecciated part consists of angular to subangular andesite fragments generally smaller than 6 cm in a matrix of similar composition suggestive of an autobreccia. This lithofacies is found in the lower part of the unit. A *matrix-supported conglomerate* is the second lithofacies. It contains subrounded to subangular pebbles and cobbles generally less than 4 cm in size and is poorly sorted in a fine-grained ash matrix. The clasts are composed of gray to dark-gray andesite and weather to a brown to reddish-brown color. The middle andesite series, as defined by Barkmann and others (2018) and herein, is correlative with the lower member of the Thirtynine Mile Andesite of Epis and Chapin (1974). On the Antero NE quadrangle, the unit yielded an $^{40}Ar/^{39}Ar$ age of 34.44+/-0.05 Ma (Barkmann and others, 2018). It nonconformably overlies the Proterozoic rocks. Rockfall is a hazard on slopes greater than 30 degrees. The middle andesite series is over 100 m thick in the east-central part of the map area.

₱bbam — **Volcanic breccia of Buffalo Gulch and middle andesite series, undifferentiated** — Volcanic breccia, andesite, and volcaniclastic conglomerate. Thickness is approximately 100 m. Shown only on cross-section.

₱wm — **Wall Mountain Tuff (Eocene)** — Red, purple, gray, pink, and brown rhyolitic crystal and vitric welded tuff and black vitric welded tuff (vitrophyre). The upper *rhyolitic crystal and vitric welded tuff* is poorly to very poorly sorted with medium-grained, euhedral, translucent sanidine constituting up to 35% of the overall composition, supported by a matrix of very fine-grained vesicular ash and fine-grained biotite making up <1% of the overall composition. The matrix has eutaxitic texture created by crushed pumice lapilli, typically oriented parallel to bedding. The tuff is typically irregularly bedded in 1 cm to 10 cm beds, but varies from very thinly-bedded to massive and locally consists of thinly-laminated low-angle cross beds. Welding of the tuff increases with depth in the flow. The *black basal vitrophyre* is poorly to very-poorly sorted, with medium-grained, euhedral acicular and elongate-columnar crystals of translucent sanidine supported in a matrix of black glass. The vitrophyre contains elongate tan to yellow clay fiamme averaging 1 cm in width and 4 cm in length with some up to 15 cm in length. The vitrophyre weathers into smooth, rounded outcrops the size of large boulders. Its upper contact with the welded tuff is sharp and averages 1 to 2 m in exposed thickness. It is exposed in two small, isolated outcrops in the NE ¼ sec. 6, T 14 S, R 75 W and is not mapped separately. The Wall Mountain Tuff was forcibly emplaced onto the western flanks of the Proterozoic uplifts within the quadrangle, and into their paleodrainages. It forms ridges reminiscent of flatirons. Pervasive orthogonal jointing and fractures, coupled with differential weathering along eutaxitic texture, cause the unit to weather into semi-elongate blocks, ropy and log-like in texture. This differential weathering coupled with irregular bedding planes creates outcrops of large broken and tilted blocks. McIntosh and Chapin (2004) determined an $^{40}Ar/^{39}Ar$ age of 36.69+/-0.09 Ma for the Wall Mountain Tuff. Where underlying Proterozoic units have eroded away, the unit is prone to blocky rockfall on slopes. The unit varies dramatically in exposed thickness from less than 1 m to 15 m on the east side of the Agate Creek fault and the west side of the Rye Slough fault. In the area between these two faults, it is about 90 m thick.

PPmm — **Upper Minturn and lower Maroon formations, undivided (Middle Pennsylvanian to Lower Permian?)** — Orangish-brown arkosic sandstone and conglomerate. Sand grains are medium to coarse, and gravel is granule- to pebble-sized. The sandstone and conglomerate occur in planar beds about 5 to 20 cm thick, and in sets of trough cross-beds about 15 cm thick. On the northwest side of the outcrop in NE ¼ sec. 12, T 14 S, R 76 W, these rocks are altered; the feldspars have been turned into clay, and large amounts of interstitial silica are present. Mounds of dolomite are interbedded with the sandstone and conglomerate, and these are described separately below. Outcrops of unit PPmm form isolated hills that stand above the surrounding topography. They nonconformably overlie Proterozoic intrusive igneous and metamorphic rocks on the Hartsel uplift, east of the Rye Slough fault. Rockfall is a hazard on slopes greater than 30 degrees. The thickness exposed in outcrops is approximately 12 to 18 m, but the thickness in the subsurface is probably greater.

PPmmc — **Upper Minturn and lower Maroon formations, unnamed dolomite beds** — Medium-gray, finely crystalline dolomite that weathers to tan and contains ghosts of crinoid stems, bryozoa, and horn corals. The dolomite is massive, and occurs in mound-shaped outcrops. Rockfall is a hazard on slopes greater than 30 degrees. The thickness exposed in outcrops is approximately 6 m, but the thickness in the subsurface could be greater.

₱PP — **Echo Park Alluvium (?), Maroon, and Minturn formations, undifferentiated** — Arkosic sandstone, conglomerate, siltstone, and shale with minor limestone. Thickness is approximately 45 to 490 m. Shown only on cross-section.

Pb — **Belden Formation (Lower Pennsylvanian)** — Dark-gray, dolomitic shale that is very well indurated, and is extensively fractured. In the vicinity of the Rye Slough fault, it is altered to dark maroon and greenish-brown colors. Very limited outcrop exposures occur in the east side of the ridge of Paleozoic rocks in the southwestern part of the quadrangle. It disconformably overlies the Leadville Limestone and is in fault contact with the Wagontongue Formation. Approximately 45 m of Belden Formation are exposed on the quadrangle. A complete section of the Belden Formation is about 280 m thick in the adjoining Antero Reservoir quadrangle (Kirkham and others, 2012).

Ml — **Leadville Limestone (Lower Mississippian)** — Medium-gray, smooth-weathering micritic limestone in beds 15 cm to 1 m thick. Some beds are internally laminated, and others appear massive. Nodules and lenses of orangish-brown chert are common, especially at the top of the formation. Blocks of fine-grained, well-indurated, quartz sandstone occur at the Leadville-Belden contact, but no outcrops were found. The Leadville Limestone weathers into large blocks, and rockfall is common on slopes greater than 30 degrees. It disconformably overlies the Dyer Dolomite, and is disconformably overlain by the Belden Formation, or is in fault contact with the Wagontongue Formation. Thickness is approximately 91 m.

Dd — **Dyer Dolomite (Upper Devonian)** — Light-tan, orangish-tan, and greenish-tan, thinly bedded, microcrystalline dolomite. A 0.3 m bed of massive gray and orange chert occurs at the top of the formation. The Dyer Dolomite disconformably overlies the Fremont Formation. Rockfall is a hazard on slopes greater than 30 degrees. Thickness is approximately 30 m.

Of — **Fremont Formation (Upper Ordovician)** — Medium-gray, microcrystalline dolomite that weathers light gray. It occurs in beds about 15 cm thick. Fossil hash was observed near the base of the formation. Invertebrate burrows and trails approximately 2 mm in diameter were observed on bedding planes. The Fremont Formation disconformably overlies the Harding Sandstone. Rockfall is a hazard on slopes greater than 30 degrees. Thickness is approximately 91 m.

Oh — **Harding Sandstone (Upper Ordovician)** — Pale-pink to reddish-pink, fine-grained quartz sandstone that is silica cemented and breaks across grains. It occurs in beds about 15 cm to 1 m thick. The formation resists erosion and forms ridges. It disconformably overlies the Manitou Formation. Rockfall is a hazard on slopes greater than 30 degrees. Thickness is approximately 23 m.

Om — **Manitou Formation (Lower Ordovician)** — Grayish-tan, thinly bedded, microcrystalline dolomite with horizons of orangish-brown or white chert and chert breccia. Invertebrate trails, approximately 2 to 4 mm in diameter, are common on dolomite bedding planes. The formation nonconformably overlies Proterozoic intrusive igneous and metamorphic rocks. Rockfall is a hazard on slopes greater than 30 degrees. Thickness is approximately 55 m.

Yi — **Porphyritic intrusion (Mesoproterozoic?)** — Dark-green biotite gabbro porphyry that weathers black to brown. The unit is composed of up to 50% biotite phenocrysts averaging 10 mm diameter in a fine- to medium-grained groundmass of plagioclase, biotite, minor quartz, and very fine-grained green accessory minerals. The unit weathers readily and forms a valley within the intruded Proterozoic units. Outcrops consist of rounded 0.5 m mounds that weather to gray gravel. Contacts with intruded units are covered and any orientation is masked by extensive weathering. The unit forms one dike on the north-central border of the quadrangle where it intruded units Ya and YXg near a shear zone.

Yp — **Pegmatite (Mesoproterozoic)** — White and light-pink, pegmatitic alkali feldspar granite and granite that weathers white. Primarily composed of centric zones of milky-white quartz, bordered by zones of light reddish-pink potassium feldspar, white plagioclase, silver to brown muscovite and, less commonly, medium-grained black biotite and very fine-grained gray accessory minerals. Muscovite typically comprises 1% of total composition. Crystal sizes of euhedral quartz and potassium feldspar average 10 cm but can be up to 50 cm in diameter. Potassium feldspar is commonly perthitic. Muscovite crystals average 1 cm in diameter, with books up to 0.6 m in diameter. Pegmatites form ridges and weather to float of angular cobbles on hillsides. They are commonly associated with small bodies of light-pink to gray, fine-grained, equigranular aplite and occur more frequently in unit Ya than in unit Ygp. Pegmatites are pervasive in the Proterozoic units and vary in size; only those greater than 1 m in width are shown on the map. They average 1.5 m in thickness and 30 m in length.

Ybd — **Brittle-ductile shear zone microbreccia (Mesoproterozoic)** — Predominantly medium to very coarse-grained microbreccia. The unit is matrix supported and very poorly sorted with framework clasts of predominantly subangular, medium-grained, light to reddish-pink alkali feldspar granite averaging 2 cm in diameter; medium-grained pink potassium feldspar; and gray quartz in a matrix of very fine-grained gray and brown mica. Feldspar grains are commonly weathered to white clay on exposed surfaces. Breccias form mounds that are less than 0.5 m wide, and are exposed over distances of approximately 50 m. Ductile areas within brittle-ductile zones include light-brown mylonitic muscovite schist with reddish-pink breccia streaks of potassium feldspar averaging 1 mm in thickness, and gold-brown phyllonite. Ductile areas also form outcrops that are less than 0.5 m wide, and are exposed over distances of 10 m or less. Most exposures of the unit contact are not well-exposed; only the contact on the west side of the uplift in the NE ¼ sec. 6, T 14 S, R 75 W was mapped. Brittle-ductile zones occur exclusively in Ya and represent the youngest deformation within the Proterozoic units.

Ya — **Alkali feldspar granite (Mesoproterozoic)** — Light-pink to light-gray, fine- to medium-grained equigranular alkali feldspar granite and granitoid that weathers pink to red. The unit is composed primarily of subhedral to anhedral gray and translucent quartz, pink and gray potassium feldspar and up to 10% either biotite or muscovite; locally, biotite is predominant. Whole-rock composition by weight percent is 79.4% SiO_2, 11.75% Al_2O_3, 1.15% Fe_2O_3, 0.4% CaO, 0.13% MgO, 2.03% Na_2O, and 6.5% K_2O. After Frost and others, (2001, 2008, 2011) Ya is ferroan, alkali-calcic, and peralkaline. Unit is commonly associated with aplite and pegmatites and commonly exhibits subhedral very coarse to pegmatitic milky and translucent quartz. Where foliated, foliation is delineated by dimensional preferred orientation of biotite; fewer outcrops have penetrative lineation. Locally, outcrops contain dimensional preferred orientation foliation of crosses of black, tabular biotite up to 2 cm in length. The two youngest shear zones occur within the unit. Brecciation and ductile deformation, up to 20 m in total width, occur within these zones. The unit is pervasively jointed by two sets of X-intersecting joints and joint planes are very smooth and angular. It is highly resistant to weathering and underlies sharp ridges and ledges along slopes of Ygp. The unit weathers to distinctly angular gravel and cobbles on hillsides. The unit discordantly intrudes Ygp and is the Proterozoic unit most commonly underlying unit PEwm. Sample 2244, taken in the NW ¼ sec. 8, T. 14 S., R. 75 W., yielded an $^{40}Ar/^{39}Ar$ date of 1.379+/-0.003 Ga.

Yd — **Ductile shear zone mylonites (Mesoproterozoic)** — Mylonite, grading from protomylonite to mylonite across an average thickness of 1.5 m. Ultramylonites were observed in both Ygp and YXgg. Their average thickness is 5 cm, and they are most commonly located centrally within mylonites averaging 1 m in thickness. Mylonites typically contain sigma type porphyroclasts of pink potassium feldspar and less commonly, delta type. Sigma and delta type porphyroclasts in shear zones indicate the rate of recrystallization was greater than the rate of strain. Porphyroclasts range in size from 1 cm to 5 cm. Like brittle-ductile zones, ductile zones are typically more weathered than surrounding undeformed rock, but they are much better exposed and typically crop out as localized areas of low relief or irregularly spaced boulder-sized outcrops. Ductile shear zones occur in units YXg, Ygp, and YXgg. They are continuous and occur in parallel sets with the exception of one set of anastomosing mylonites near the northern map border in units YXg and Ygp.

Ygp — **Biotite granite porphyry and granitic gneiss (Mesoproterozoic)** — Black and gray, weakly to strongly foliated biotite granite porphyry and granitic augen gneiss that weathers gray to brown. Locally granodiorite. Groundmass is typically composed of fine- to medium-grained, subhedral, translucent and gray quartz, white and pink potassium feldspar, white plagioclase, and biotite. Phenocrysts are light-gray and pink subhedral potassium feldspar. The average diameter is 2 cm, but crystals can be up to 5 cm in diameter. They commonly cleave out of the unit with perfect 90 degree cleavage. Where gneissic, porphyroclasts and augen are also primarily pink potassium feldspar, and average 3 cm. Whole-rock composition by weight percent is 70.9% SiO_2, 12.95% Al_2O_3, 4.4% Fe_2O_3, 2% CaO, 1% MgO, 2.46% Na_2O, and 3.69% K_2O. After Frost and others (2001, 2008, 2011), Xgp is ferroan, calc-alkalic, and peraluminous. Two sets of equally spaced joints with X-intersections are dominant and present in all outcrops though many are weathered and rounded. The unit is altered by at least five ductile shear zones; these mylonites average 1.5 m in thickness and 20 m in length. The unit forms both massive rounded ridges and slopes where it is more highly weathered. In the northern part of the mapped area, this unit is the primary ridge-former and dominates the landscape. Both weathering and metamorphism increase within the unit to the south, where it is primarily gneiss and prone to forming slopes and grus. It weathers with a consistent lumpy, porphyritic texture into well rounded and sometimes bouldery outcrops and wide fins. Weathering rinds and iron-oxide staining are common. It is discordantly intruded by dikes of Ya, varying in size from less than 1 m to more than 4 m in thickness. Pegmatites, though infrequent, have an average thickness of 30 cm. This is the most widespread Proterozoic unit on the quadrangle. Sample 2153, taken in the SW ¼ sec. 8, T. 14 S., R. 75 W., yielded an $^{40}Ar/^{39}Ar$ date of 1.380+/-0.003 Ga.

YXg — **Granite (Mesoproterozoic or Paleoproterozoic)** — Light pink-gray, medium- to coarse-grained, massive to weakly foliated biotite granite that weathers red. Locally the unit is alkali feldspar granite or quartz monzonite. It is equigranular with euhedral to subhedral gray quartz, light-pink potassium feldspar, white plagioclase, and black biotite groundmass crystals averaging 2 mm in diameter. Locally it is porphyritic, with subhedral potassium feldspar phenocrysts averaging 8 mm diameter. Where weakly foliated, foliation is created by dimensional preferred orientation of biotite aggregates. Myrmekitic intergrowths in sodic plagioclase are common. Whole-rock composition is 70.4% SiO_2, 13.5% Al_2O_3, 4.8% Fe_2O_3, 1.76% CaO, 1.06% MgO, 2.61% Na_2O, and 4.01% K_2O. Unlike other Proterozoic units within the quadrangle, it weathers to low-lying smooth mounds, lacks dominant jointing, and crops out only in an area on the north-central border of the quadrangle.

YXfg — **Fine-grained granite (Mesoproterozoic or Paleoproterozoic)** — Light-gray, fine-grained, moderately foliated, weakly lineated granite and granodiorite that weathers gray. The unit is equigranular, with a groundmass of subhedral gray quartz, pink and brown potassium feldspar, white plagioclase, and biotite. Whole-rock composition is 69.7% SiO_2, 13.7% Al_2O_3, 4.58% Fe_2O_3, 1.93% CaO, 1.08% MgO, 2.17% Na_2O, and 4.81% K_2O. The unit weathers along foliations into very smooth slabs averaging 2 cm in thickness. It forms an isolated ridge where it crops out as 1-m -diameter boulders on the ridge top and thin, 1-m-thick rounded slabs along slopes.

YXgg — **Granitic gneiss (Mesoproterozoic or Paleoproterozoic)** — Light-gray, medium- to coarse-grained, moderately to strongly foliated, biotite granitic gneiss and granite porphyry that weathers red-brown. The unit is composed primarily of subhedral to anhedral white and gray potassium feldspar, gray quartz, white plagioclase, biotite, and accessory hornblende. It is porphyritic with subhedral megacrysts of gray and white potassium feldspar averaging 3 cm in diameter. Whole-rock composition by weight percent is 70.9% SiO_2, 12.9 % Al_2O_3, 3.29% Fe_2O_3, 1.73% CaO, 0.52% MgO, 3% Na_2O, and 5.11% K_2O. The unit is marked by enclaves of quartz syenite and alkali feldspar quartz syenite composition far more resistant to weathering than the rest of the unit. These spheroidal to oblate enclaves are dominated by medium to coarse-grained microcline with fine-grained biotite. Enclaves average 5 cm in diameter with a maximum size of 15 cm. The unit is mostly gneissic and the enclaves commonly delineate an S-C fabric where they are flattened and stretched. Two joint sets with X-intersections are pervasive; the vertical set is more closely spaced, causing the unit to weather into fins less than 1 m wide. The unit commonly contains aplite dikes and pegmatites typically parallel to foliation averaging 10 cm in thickness. Some of the aplite dikes are tightly folded and in one isolated zone of semi-brittle deformation, have cm-scale offset en-echelon faulting. The unit is also altered by four parallel mylonites and ultramylonites averaging 1 m and 10 cm in thickness, respectively, that extend parallel along the length of the exposed unit. Outcrops are highly weathered with broken surfaces coated in iron oxide staining and feldspars weathered to white clay. Though limited in extent, this unit forms very large, 5 m to 10 m tall and 20 m long, rounded ridges of fins with a nodular texture created by the differential weathering of the oblate enclaves.

YXu — **Proterozoic rocks, undifferentiated** — Granite, granite porphyry, and granitic gneiss with minor pegmatite and gabbro, cut by brittle-ductile and ductile shear zones. Shown only on cross-section.

MAP SYMBOLS

Contact — Approximately located

D / U — **Fault** — Long dashed where approximately located, short dashed where inferred, dotted where concealed, queried where existence is questionable; U = upthrown side, D = downthrown side at surface where known

Anticline — Long dashed where approximately located, short dashed where inferred, dotted where concealed; arrow shows direction of plunge

Syncline — Long dashed where approximately located, short dashed where inferred, dotted where concealed; arrow shows direction of plunge

Closed depression

Depression

A — A' **Alignment of cross section**

AM 2153 **Ar-Ar sample**

AG OSL 1 **OSL sample**

Uranium exploration drill hole

44 **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 of dip as estimated from aerial photographs

14 **Strike and dip of delta foresets** — Showing direction and angle of dip in degrees

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

30 **Strike and dip of volcanic layering** — Showing direction and angle of dip in degrees