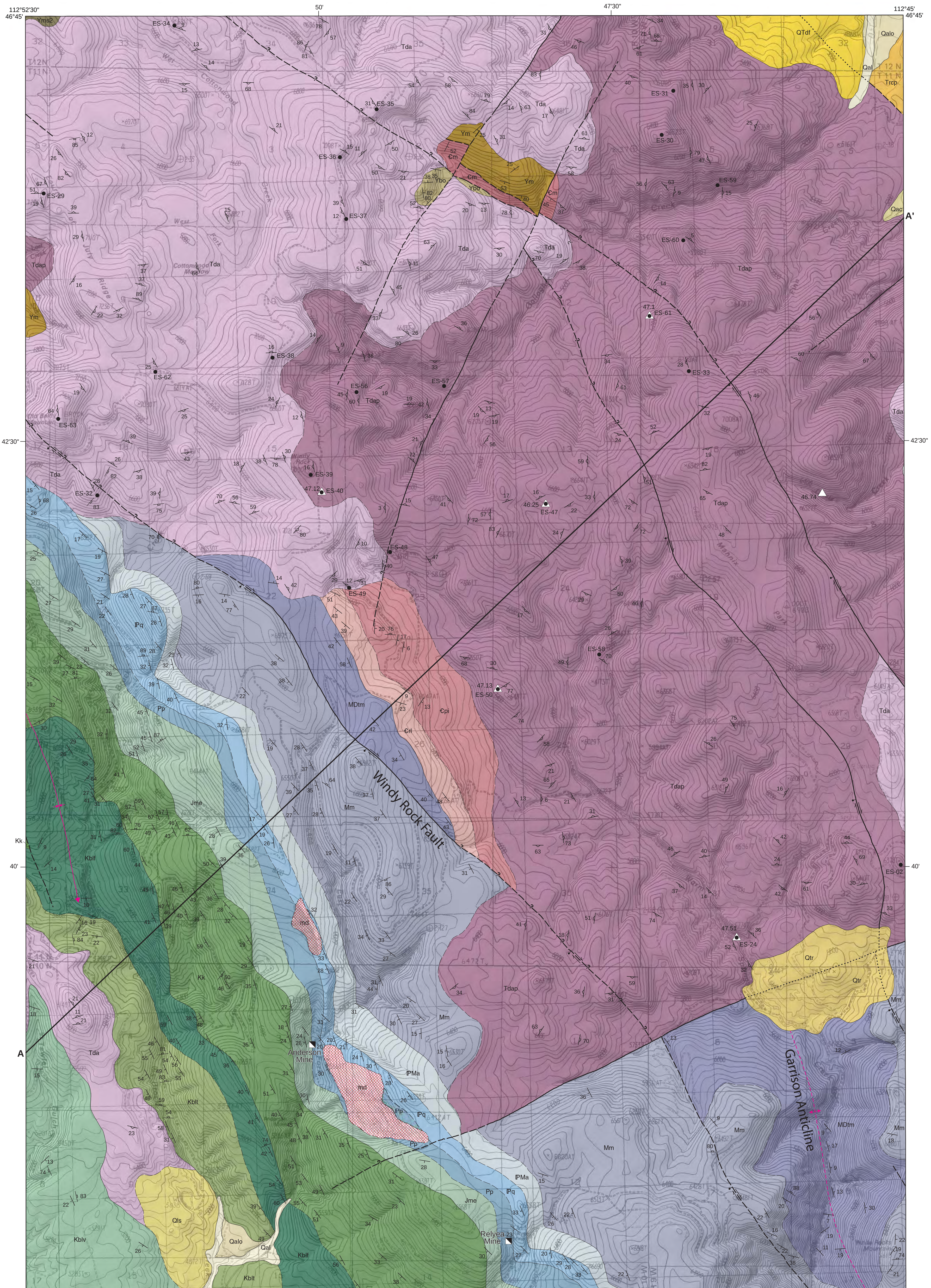
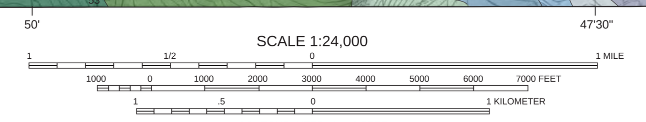
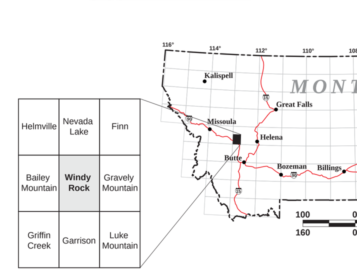


Base map produced by the United States Geological Survey
Control by: USGS, NOS/NOAA, and USFS
Compiled from aerial photographs taken 1984
Field checked: 1985 Map edited: 1989
Projection: Lambert Conformal Conic
Grid:1000 meter Universal Transverse Mercator Zone 12
UTM grid declination: 1° 19' West
1989 Magnetic North Declination: 16° 30' East
Vertical Datum: National Geodetic Vertical Datum of 1929
Horizontal Datum: 1927 North American Datum

Shaded relief created from 10 meter digital elevation model from U.S. Geological Survey National Elevation Dataset.





INTRODUCTION

The Windy Rock 7.5' quadrangle covers part of the eastern Garnet Range in west-central Montana, near the towns of Avon and Garrison in Powell County (fig. 1). The general geologic setting is complex and at the junction of several tectonic elements including the Lewis and Clark Line, the Great Falls tectonic zone, and the Helena Salient of the Sevier fold-and-thrust belt (McDonald and others, 2015). The quadrangle is also located northeast of the Anaconda Metamorphic Core Complex (AMCC; O'Neill and others, 2004; Foster and others, 2010) and within the regionally extensive Cenozoic Challis–Kamloops volcanic belt (Mosolf, 2015).

GEOLOGIC SUMMARY

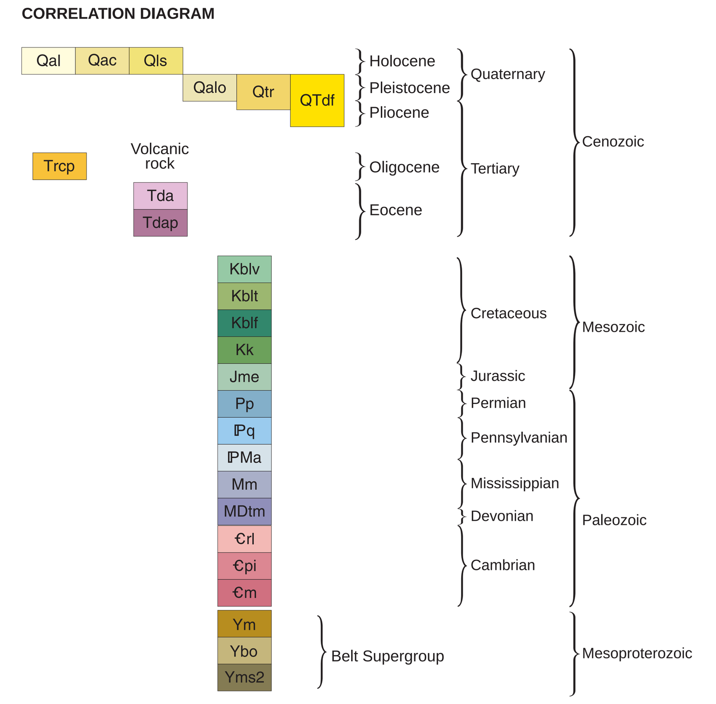
The Windy Rock quadrangle is underlain by Tertiary volcanic rocks resting on an unconformity that truncates folded and faulted Mesoproterozoic through Late Cretaceous sedimentary and metasedimentary strata. Mesoproterozoic rocks of the Belt Supergroup are the oldest units and occur as isolated and faulted outcrops in the northern part of the map area. A thick succession of Cambrian through Cretaceous continental and marine strata underlies the southern part of the map area and is generally tilted to the southwest (fig. 2). Several adits and abandoned phosphate mines, including the Anderson and Relyea mines, are located along the Permian–Pennsylvanian boundary (map units Pp and IPq). Eocene volcanic deposits unconformably overlie Mesoproterozoic–Cretaceous strata and appear to thicken eastward. Volcanic deposits are mostly effusive aphanitic and porphyritic dacite and trachydacite lava flows (table 1, fig. 3) with minor amounts of intercalated volcanic ash. The porphyritic lavas (Tdap) yielded six U-Pb zircon ages spanning 46.25 ± 0.27 to 47.51 ± 0.21 Ma (table 2). The youngest map units in the quadrangle are Quaternary and Tertiary surficial deposits.

Mesoproterozoic through Late Cretaceous strata are tilted and deformed in upright folds (at outcrop- to map-scale) that plunge gently to the south–southeast (fig. 2); the Late Cretaceous Vaughn Member of the Blackleaf Formation is the youngest unit folded in the map area. Fold structures are displaced by northwest- and northeast-striking, high-angle, oblique-slip faults interpreted to be kinematically linked transtensive structures. The Windy Rock Fault is the most prominent northwest-striking fault in the quadrangle, and exhibits right-lateral, oblique-slip displacement of Devonian through Eocene rocks. The fault has a minimum of 360 m (1,180 ft) of normal dip separation in the Windy Rock quadrangle (A–A'), and approximately 2.6 km (1.6 mi) of right-lateral strike separation in the adjacent Luke Mountain 7.5' quadrangle (McDonald and others, 2015). Northeast-striking faults have a minimum of 365 m (1,200 ft) of vertical displacement and an undetermined but minimal amount of strike separation. These northeast-striking faults guided the development of hydrothermal systems and related Quaternary (?) travertine deposits near the headwaters of Warm Springs Creek (fig. 1). Major extensional faults in the quadrangle are interpreted to be parallel with and reactivate transpressive faults formed during Late Cretaceous crustal shortening within the Lewis and Clark Line (Sears and Hendrix, 2004). Transtensive deformation and the eastward thickening of the Eocene volcanic units suggest volcanism was contemporaneous with the onset of local crustal extension and rapid exhumation (53–39 Ma) of the nearby AMCC.

PREVIOUS MAPPING

Parts of the Windy Rock quadrangle were included on geologic maps by Callmeyer (1984, scale 1:41,700), French (1979, scale 1:62,500), and Lewis (1998, scale 1:250,000). Several of the unit descriptions and thicknesses of the Paleozoic and Mesozoic stratigraphy were based upon Gwinn (1961), Kauffman and Earll (1963), and Sears and others (2000).

CORRELATION DIAGRAM



MAP SYMBOLS

Contact: dashed where approximately located

Fault: dashed where approximately located; dotted where concealed; bar and ball on downthrown side; arrows indicate relative lateral movement

Anticline axial trace: dashed where approximately located

Plunging syncline axial trace

Strike and dip of inclined beds

Strike and dip of fractures

Strike and dip of volcanic foliation

U-Pb zircon age (Ma)

Sample location

Mine tailings

Historic mine

DESCRIPTION OF MAP UNITS

Qal **Alluvium (Quaternary: Holocene)**—Gravel, sand, silt, and clay along streams and their tributaries. Clasts are generally cobble size and smaller, and are rounded to subrounded.

Qac **Alluvium and colluvium (Quaternary: Holocene)**—Silt, sand, granules, and pebbles deposited on slopes by sheetwash alluvium incorporated with locally derived fine-grained colluvium. Thickness generally less than 8 m (20 ft).

Qls **Landslide deposit (Quaternary: Holocene or Pleistocene)**—Mass-wasting deposits of rotated or chaotic strata and angular rock fragments. Landslide deposits were only observed in the southwest part of the map area.

Qalo **Alluvium: older than Qal (Quaternary: Pleistocene)**—Unconsolidated clastic deposits beneath floodplains; assumed to be similar to Qal but generally covered with fine-grained floodplain deposits.

Qtr **Travertine (Quaternary)**—Coarsely crystalline calcium carbonate beds 3–50 cm thick that are commonly disturbed/chaotic. Deposits form a large, conspicuous mound near upper Warm Springs Creek, overlie Eocene volcanics and Mississippian through Devonian strata, and conceal a northeast-trending fault. Carbonate deposition is no longer active and a karst topography covered by soil has developed on the surface.

QTdf **Debris-flow deposit (Quaternary or Tertiary)**—Matrix-supported deposits that include many angular and subangular boulders and smaller clasts derived from volcanic deposits upslope. Mapped primarily in the northeast part of the map area on the basis of boulder lag on a topographically irregular surface.

Trcp **Cabbage Patch member of the Renova Formation (Tertiary: Oligocene and/or Eocene)**—A complex of gastropod-bearing marlstone, thinly bedded limestone, tufa, travertine, and local gastropod coquina that in many places overlies a coarse-grained sandstone with plant impressions, petrified wood, and associated shale. Exposed thickness in the adjacent Gravely Mountain 7.5' quadrangle (Mosolf and Vuke, in review) is approximately 90 m (300 ft).

Tda **Aphanitic dacite lava flows (Tertiary: Eocene)**—Gray and dark gray weathering, aphanitic to slightly porphyritic dacite to trachydacite lava flows (table 1, fig. 3) with autobrecciated flow bottoms overlain by massive, coherent flow interiors; zones of vesiculation are rarely preserved. Individual flows commonly exhibit distinctive flow banding and form flaggy, angular talus, often with red iron staining on parting surfaces. Aphanitic lavas exhibit a strong trachytic texture consisting mainly of plagioclase microlites, but also include pyroxene, magnetite, and volcanic glass. Slightly porphyritic flows have a similar trachytic texture and groundmass mineralogy, but contain subhedral to euhedral phenocrysts of plagioclase, hornblende, and some biotite. Significant exposures occur in the northwest part of the map area where they overlie the dominantly porphyritic lavas (Tdap) and Phanerozoic through Proterozoic units. Thickness is approximately 0–500 m (0–1,640 ft).

Tdap **Porphyritic dacite lava flows (Tertiary: Eocene)**—Gray, green, and red weathering dacite to trachydacite lava flows (table 1, fig. 3) with a distinct coarse, porphyritic texture. Lava flows contain subhedral to euhedral phenocrysts of plagioclase (up to ~5 mm) and minor amounts of amphibole, biotite, and quartz. The aphanitic groundmass commonly has a trachytic texture and consists mainly of aligned microlites of plagioclase, but also includes amphibole, biotite, and magnetite. Carapaces of autobreccia several meters thick commonly encompass coherent interiors of individual lava flows. This unit weathers into blocks or plates, with some outcrops forming hoodoos and spires. U-Pb zircon ages obtained from six samples range from 46.25 ± 0.27 to 47.51 ± 0.21 Ma (table 2). Thickness of this unit is approximately 0–720 m (0–2,400 ft).

Kblv **Vaughn Member of the Blackleaf Formation (Upper and Lower Cretaceous)**—Siliceous, volcanic-rich deposits of gray-green, gray, and dark gray volcanic mudstone, siltstone, chert, and lithic-rich (salt-and-pepper) sandstone with several interbeds of pebble conglomerate and volcanic tuff. Chert-pebble conglomerate beds mark the base of the Vaughn Member, whereas the upper stratigraphy consists mainly of multi-colored siltstones and shales. Originally mapped as the Dunkleberg Formation by Gwinn (1961). This unit is poorly exposed with a few scattered outcrops occurring in the southwest corner of the map area. Stratigraphic thickness is approximately 460–520 m (1,510–1,706 ft).

Kblt **Taft Hill Member of the Blackleaf Formation (Lower Cretaceous)**—Tan to light gray, calcareous, cross-bedded sandstone interbedded with gray to green siltstone and mudstone. Distinct lenticular volcanic-rich deposits occur in the upper ~60 m (197 ft). Resistant outcrops of calcareous sandstone are best observed above the road in the Brock Creek drainage in the southwest part of the map area. Total stratigraphic thickness is approximately 275–305 m (902–1,000 ft).

Kblf **Flood Member of the Blackleaf Formation (Lower Cretaceous)**—The upper 140–150 m (460–492 ft) consists of poorly exposed, dark gray to black, non-calcareous, fissile shale with minor thin beds of carbonaceous siltstone and fine-grained, calcareous, ripple-bedded sandstone. The lower 70–80 m (230–262 ft) consists of tan, gray, and yellow-brown, often iron-oxide stained, sandy limestone, siltstone, fine-grained sandstone, and resistant quartzite; the lower clastic interval commonly forms a prominent ridge and dip slope in the southwest part of the map area. Excellent roadcuts in and outcrops of the Flood Member occur in the upper Brock Creek drainage.

Kk **Kootenai Formation, undivided (Lower Cretaceous)**—Alternating deposits of mudstone, siltstone, limestone, salt-and-pepper sandstone, and conglomerate that compose four informal members including (from top to bottom) the upper calcareous, upper clastic, lower calcareous, and lower clastic members. The upper calcareous member is gray, fine- to medium-crystalline limestone with minor interbedded shale, siltstone, and sandstone. The top is marked by a dark gray, coarsely crystalline limestone composed almost entirely of gastropod shells. The upper clastic member consists of green, gray, and maroon siltstone and shale with a few thin calcareous salt-and pepper sandstone and limestone beds, including a distinctive flat-pebble limestone conglomerate. The lower calcareous member consists of interbedded dark gray to black, very fine-grained limestone, maroon, green, and gray shale and siltstone, and occasional beds of calcareous concretions. The lower clastic member is maroon and gray sandstone interbedded with minor shale and siltstone. The base of the Kootenai Formation is typically marked by lenticular beds of red-brown to gray conglomerate with pebbles and cobbles of black chert and white quartz or hard, silica-cemented vitreous sandstone with distinct red jasper grains. The Kootenai Formation is generally well exposed in the map area and forms prominent, alternating ridges and saddles. Total thickness is approximately 330 m (1,083 ft).

Jme **Morrison Formation and Ellis Group, undivided (Late to Middle Jurassic)**

Morrison Formation (Late Jurassic)—Poorly exposed olive green, and gray to grayish green mudstone, shale, siltstone, and minor sandstone. Siltstone near base is calcareous and flaggy bedded. Dense, salt-and-pepper sandstone and minor concretionary limestone occur in the upper part. Stratigraphic thickness is approximately 47–67 m (154–220 ft).

Ellis Group (Late to Middle Jurassic)

Swift Formation: The upper part is brown to yellowish brown, often calcareous and glauconitic, salt-and-pepper sandstone with interbedded siltstone and micaeous shale. Basal sandstone contains lenses of black chert-pebble conglomerate. Minor fossils include oyster, belemnite, and wood fragments. Thickness is approximately 35–75 m (115–246 ft).

Ellis Group (Late to Middle Jurassic) (continued)

Rierdon Formation: Dark brownish gray to dark gray calcareous shale, shaly limestone, and limestone. Shales weather yellowish gray or whitish gray. Fossil fragments and ripple marks are common on bedding planes. Brown, oolitic or sandy limestone beds mark the stratigraphic base. Thickness is approximately18–23 m (59–75 ft).

Sawtooth Formation: The lower part is dark gray to black, fossiliferous, calcareous buff-weathering siltstone; middle part is very calcareous dark gray shale or argillaceous limestone that weathers creamy white; upper part is interbedded calcareous shale, siltstone, and limestone. Approximate thickness is 75 m (246 ft).

Pp **Phosphoria Formation (Permian)**—Bluish-gray and brown weathering sandstone, shale, bedded chert, and oolitic phosphatic rock. The Phosphoria Formation is poorly exposed and commonly forms topographic saddles. Relatively good exposures occur near the Luke Mine in the adjacent Luke Mountain 7.5' quadrangle. Extensively mined for phosphate in the map area. Thickness is approximately 80 m (262 ft).

IPq **Quadrant Formation (Pennsylvanian)**—White to tan, fine- to medium-grained, vitreous quartzites that are poorly bedded to massive and locally brecciated. Weathers to a greenish gray or rusty brown surface spotted by black lichen. The Quadrant Formation is an excellent marker horizon that is ridge-forming and easily distinguishable from the other map units. Thickness estimated to be 60 m (197 ft).

IPMa **Amsden Formation (Pennsylvanian and Mississippian)**—Reddish brown, fine-grained sandstone, calcareous siltstone, shale, and limestone. A thin interval of pebble conglomerate marks the top of the formation. The Amsden Formation is poorly exposed in the map area and is commonly distinguished by red-brown soil or a recessive interval between the underlying Madison Group and the overlying Quadrant Formation. Thickness estimated to be 90 m (295 ft).

Mm **Madison Group, undivided (Mississippian)**—Thick sequence of limestone, limestone breccia, and chert that is generally resistant and forms prominent ridges, cliffs, and hoodoos. Excellent exposures of the Madison Group occur along the Warm Springs Creek drainage in the southeast part of the map area.

Mission Canyon Formation—Upper part is light to medium gray limestone breccia with interbedded medium-bedded limestone and dolomitic limestone. Breccias contain angular limestone and siltstone clasts in an orange- and red-stained matrix. Lower part is light to dark gray, partly cherty, medium- to massive-bedded limestone and minor dolomite. Typically fossiliferous and oolitic. Weathers medium to light gray. Thickness is approximately 250 m (820 ft).

Lodgepole Formation—Dark gray, fossiliferous, thin-bedded limestone and silty limestone. Abundant interbeds of dark gray to black chert nodules, ribbons, and beds—especially in lower part of the formation. The upper part is more fossiliferous with thicker beds and some breccia. Weathers light to medium gray. Thickness is approximately 270 m (885 ft).

MDtm **Three Forks, Jefferson, and Maywood Formations, undivided (Early Mississippian and Upper Devonian)**—Thick sequence of shale, siltstone, limestone, and dolomite. Limestone and dolomite of the Jefferson Formation commonly form ridges, cliffs, and spires. The Three Forks and Maywood Formations are generally poorly exposed and recognized only by float. Most of the Upper Devonian sequence can be observed in the Warm Springs Creek drainage in the southeast part of the map area.

Three Forks Formation (Early Mississippian and Upper Devonian)—Siltstone and sandstone, micritic limestone, and local lenses of limestone breccia. Siltstones and sandstones are moderate reddish orange, flaggy and calcareous with angular gypsum casts on surfaces. Limestone is wavy laminated and weathers grayish pink to grayish yellow, often with moderate reddish orange stain and smooth surfaces. Poorly exposed and recognized only by red soil and float. Estimated thickness 0–45 m (0–148 ft).

Jefferson Formation (Upper Devonian)—Upper limestone member is light to dark gray and gray brown, thick-bedded to massive, and often brecciated. Commonly forms towers and spires. Approximate stratigraphic thickness is 245 m (804 ft). The middle dolomite member is dark gray to gray-brown to black, saccharoidal with a strong petroliferous fetid odor, and approximately 90 m (295 ft) thick. The lower limestone and dolomite member is dark gray, finely crystalline, and thin- to thick-bedded with abundant orange-yellow stringers and lacework. Typically has moderate petroliferous odor. Thickness estimated to be 180 m (590 ft).

Maywood Formation (Upper Devonian)—Poorly exposed thin-bedded gray, reddish gray, grayish green, and yellow dolomitic shale and siltstone, silty dolomite, and sparse gray limestone. The contact with the underlying Cambrian Red Lion Formation is often difficult to locate. Estimated stratigraphic thickness is 100 m (330 ft).

Crl **Red Lion Formation (Upper Cambrian)**—Upper part is light to dark gray micritic limestone with interbedded, thin, and discontinuous siliceous layers. The siliceous layers stand in relief on weathered surfaces, imparting a wavy, ribbon-like structure to the bedding. Flat-pebble conglomerate is relatively common. Lower part is a distinct red, reddish brown, and yellowish brown siltstone and shale, that is often calcareous with locally abundant trace fossils. Weathered float often displays distinct grayish red and pale red Liesegang banding. Forms saddles above the Pilgrim Formation. Stratigraphic thickness is approximately 110 m (360 ft).

Cpi **Pilgrim Formation (Upper Cambrian)**—Light to medium gray, massive to thinly laminated, thin- to thick-bedded, finely crystalline and microcrystalline dolomite with rare oncolites and abundant chert. Weathers light gray with a gritty, often faintly laminated surface. Well exposed along road in the upper reaches of Warm Springs Creek. Minimum stratigraphic thickness is 190 m (625 ft) with no base exposed.

Cm **Meagher Formation (Middle Cambrian)**—Gray to dark gray, thin- to thick-bedded micrite and biomicrite containing distinctive thin interbeds of uneven and discontinuous gold and orange weathering siliceous and argillaceous dolomite. Stratigraphic thickness in map area unknown.

Ym **McNamara Formation (Mesoproterozoic)**—Couplets and microcouplets of variegated red and green fine-grained quartzite, siltite, and waxy argillite containing diagnostic red or green chert beds and chert rip-up clasts. Mudcracks and mud rip-up clasts are common. The top part is light gray, thick-bedded, fine- to medium-grained, cross- bedded quartzite containing abundant red mud rip-up clasts, uncommon red chert rip-up clasts, and abundant thin, red, mudcracked argillite interbeds. Stratigraphic thickness in map area unknown.

Ybo **Bonner Formation (Mesoproterozoic)**—Pink to red, medium- to coarse-grained, poorly sorted, very feldspathic quartzite. Abundant trough and planar crossbeds in beds typically 0.5–1.0 m thick. Beds often separated by thin (0.1–1.0 cm) red to maroon argillite beds. Contains abundant well-rounded coarse quartz grains, and sparse subangular granules and small pebbles. Five slabbed and stained samples from the Ophir Creek 7.5' quadrangle (Lonn and Vuke, 2015) contained 50–75 percent quartz, 15–35 percent potassium feldspar, and 5–15 percent plagioclase. Stratigraphic thickness in map area unknown.

Yms2 **Mount Shields Formation, member 2 (Mesoproterozoic)**—Pink to red, poorly sorted, medium- to coarse-grained, feldspathic quartzite. Abundant planar and trough crossbeds. Contains sparse subangular granules. Lower part is thin bedded, consisting of couples of white to pink, medium-grained quartzite and thin red argillite. Bases of quartzite beds contain abundant red mud chips. The lower part was previously included in the top part of the Mount Shields Formation, member 1 of Schmidt and others (1994). Two slabbed and stained samples from the Ophir Creek 7.5′ quadrangle (Lonn and Vuke, 2015) east of the map area contained 65–75 percent quartz, 5–15 percent potassium feldspar, and 20 percent plagioclase. Difficult to distinguish from the Bonner Formation (unit Ybo). Exposed only in the extreme northwest part of the quadrangle. Thickness not determined.

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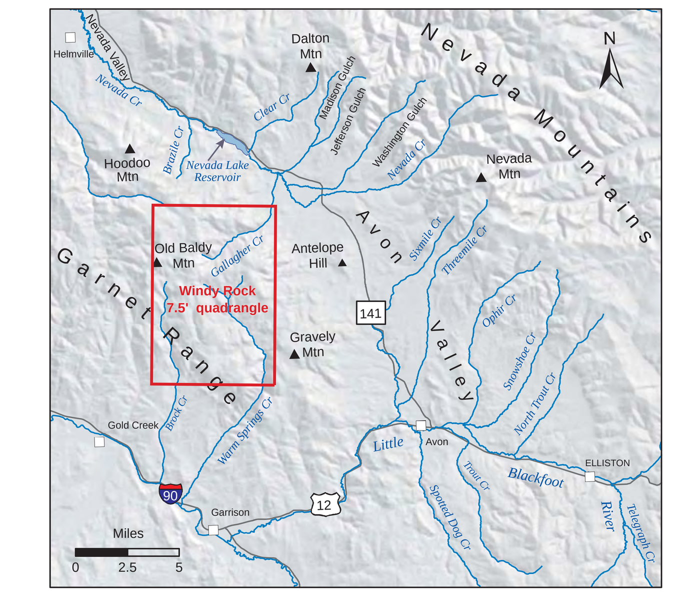


Figure 1. Location map for the Windy Rock 7.5' quadrangle.

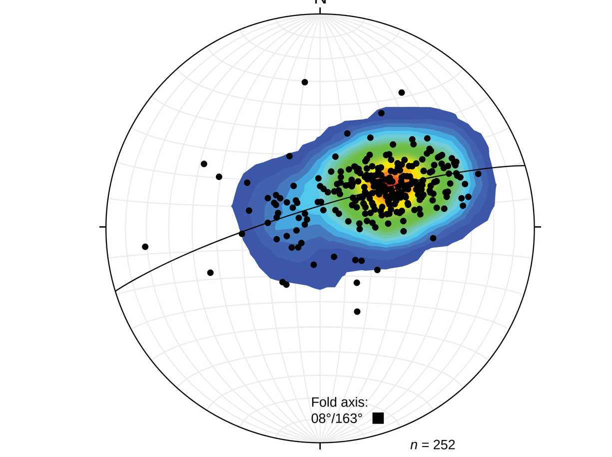


Figure 2. Lower-hemisphere projection of poles to all bedding measurements plotted on a equal-area stereonet and fit with a Kamb contour. Great circle is the cylindrical best fit of the data and the black square is the representative axis of folding in the map area.

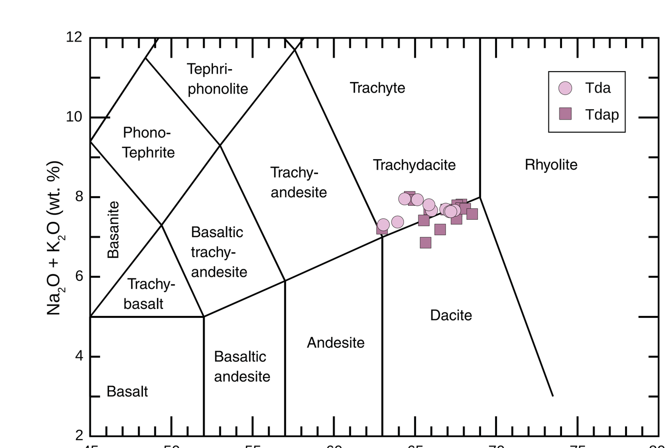


Figure 3. Whole-rock geochemical data for samples collected in the Windy Rock 7.5' quadrangle. Data are normalized and plotted on a total alkali-silica diagram ($Na_2O + K_2O$ vs. SiO_2) after Le Bas and others (1986).

Table 1. Raw bulk rock geochemical data from samples collected in the Windy Rock 7.5' quadrangle.

Sample ID	ES-02	ES-24	ES-29	ES-30	ES-31	ES-32	ES-33	ES-34	ES-35	ES-36	ES-37	ES-38	ES-39	ES-40	ES-47	ES-48	ES-49	ES-50	ES-56	ES-57	ES-58	ES-59	ES-60	ES-61	ES-62	ES-63
Map unit	Tdap	Tdap	Tda	Tdap	Tdap	Tda	Tdap	Tda	Tda	Tda	Tda	Tda	Tdap	Tdap	Tdap	Tdap	Tda	Tdap	Tdap	Tdap	Tdap	Tdap	Tdap	Tdap	Tda	Tda
Latitude	46.67	46.66	46.73	46.74	46.74	46.70	46.72	46.75	46.74	46.74	46.73	46.72	46.71	46.70	46.70	46.70	46.69	46.68	46.71	46.71	46.69	46.73	46.73	46.72	46.72	46.71
Longitude	-112.75	-112.77	-112.87	-112.79	-112.78	-112.87	-112.78	-112.85	-112.83	-112.83	-112.83	-112.84	-112.84	-112.83	-112.80	-112.82	-112.83	-112.81	-112.83	-112.82	-112.79	-112.78	-112.78	-112.79	-112.86	-112.87
Major elements (wt %)																										
SiO_2	62.70	65.10	64.07	65.75	64.20	64.64	63.33	62.73	61.49	63.46	62.16	64.90	65.46	60.53	65.92	64.37	62.34	65.40	62.60	61.93	65.95	62.96	67.08	61.97	65.38	65.17
TiO_2	0.53	0.56	0.58	0.54	0.59	0.55	0.57	0.69	0.64	0.61	0.66	0.53	0.55	0.70	0.56	0.56	0.70	0.54	0.70	0.69	0.53	0.57	0.55	0.60	0.53	0.53
Al_2O_3	15.55	15.65	16.03	15.82	15.64	15.69	15.97	16.50	15.92	16.32	16.00	15.78	15.75	16.40	15.81	15.68	15.89	15.57	15.95	15.77	15.70	15.64	15.57	16.14	15.81	15.96
FeO*	3.25	3.73	3.88	3.54	3.73	3.52	3.57	3.71	4.81	3.95	4.37	3.34	3.35	4.44	3.55	3.69	4.24	3.71	4.07	4.05	3.49	4.04	3.52	3.70	3.53	3.53
MnO	0.17	0.01	0.05	0.02	0.03	0.04	0.06	0.05	0.09	0.03	0.05	0.05	0.02	0.06	0.04	0.01	0.03	0.05	0.06	0.02	0.05	0.01	0.03	0.05	0.03	0.05
MgO	1.29	0.66	1.08	0.57	1.17	1.15	1.55	0.81	2.87	0.58	2.41	1.05	0.68	2.43	0.42	0.49	1.45	0.45	1.50	1.47	0.39	0.80	0.50	1.48	0.73	0.74
CaO	4.48	2.72	3.39	2.56	2.59	3.09	3.08	3.47	4.03	3.24	3.85	3.16	2.98	3.98	2.65	2.72	3.83	2.65	3.51	3.15	2.77	3.10	2.79	3.26	3.02	3.09
Na_2O	4.05	4.16	4.42	4.07	3.98	4.17	4.37	4.74	4.44	4.70	4.36	4.41	4.35	4.01	4.33	4.14	4.25	4.21	4.20	4.06	4.25	3.87	4.22	3.89	4.38	4.31
K_2O	3.37	3.49	3.25	3.75	3.71	3.53	3.33	3.20	2.87	3.11	3.02	3.23	3.45	3.20	3.51	3.32	3.71	3.52	3.81	3.87	3.46	3.32	3.36	2.97	3.29	3.33
P_2O_5	0.26	0.29	0.29	0.27	0.30	0.26	0.30	0.39	0.36	0.36	0.35	0.24	0.25	0.37	0.29	0.30	0.41	0.30	0.40	0.39	0.26	0.29	0.28	0.33	0.24	0.26
Sum	95.64	96.37	97.06	96.89	95.93	96.63	96.14	96.29	97.52	96.37	97.23	96.70	96.84	96.11	97.08	95.29	96.86	96.40	96.80	95.41	96.84	94.61	97.89	94.38	96.93	96.96
LOI	3.85	2.68	1.71	2.13	2.81	2.07	2.45	2.07	1.21	2.11	1.55	2.08	1.56	2.41	2.10	3.08	1.58	1.88	1.92	2.85	2.07	3.64	0.80	4.04	1.73	1.80
Trace elements (ppm)																										
Ni+	46.48	48.95	18.62	25.41	27.38	12.31	18.52	31.72	61.46	23.34	66.98	12.51	17.04	52.50	15.17	11.43	39.70	11.82	46.89	41.07	15.66	34.87	21.87	14.78	11.52	22.36
Cr+	80.07	75.16	31.42	42.06	44.42	23.34	28.76	44.23	88.55	44.23	94.86	21.67	31.91	77.22	32.90	23.54	49.05	23.25	64.32	56.15	30.14	48.17	36.25	25.51	23.34	39.99
V+	60.95	53.09	57.72	51.91	52.89	51.71	60.77	57.52	72.99	60.18	68.06	51.71	51.12	75.45	53.49	36.05	66.49	47.97	68.16	63.53	43.73	39.01	37.23	51.61	47.77	49.84
Ga+	19.62	19.50	20.88	18.72	19.80	19.40	19.50	21.37	20.39	20.29	20.00	18.62	19.90	21.28	19.50	20.78	19.80	19.60	20.49	20.00	19.80	19.90	19.80	19.21	19.60	19.21
Cu+	16.05	13.10	14.48	12.12	11.92	12.61	11.43	12.90	22.06	11.03	19.01	11.03	13.20	14.68	11.82	8.27	17.73	13.59	13.59	14.78	13.49	11.43	9.26	7.58	11.13	11.52
Zn+	75.81	71.61	80.38	83.92	78.80	93.58	77.32	95.15	105.69	92.39	88.35	78.90	75.16	79.78	93.58	74.17	104.41	87.47	81.46	82.35	88.26	84.81	61.66	71.61	76.14	78.21
La	54.82	60.76	60.21	65.28	63.91	60.52	56.29	73.23	80.73	74.42	64.16	51.28	74.91	68.91	74.61	71.02	79.20	63.90	64.27	61.22	66.66	58.52	61.03	59.16	49.91	56.66
Ce	94.70	96.69	106.92	104.67	117.57	106.53	99.90	129.57	142.04	128.27	115.84	92.33	106.45	124.41	121.62	116.28	145.17	112.34	118.35	114.21	112.70	106.94	104.58	105.36	86.51	97.68
Pr	10.86	12.04	12.10	13.34	12.67	11.96	11.71	14.64	15.63	14.39	12.98	10.02	14.12	14.32	14.48	13.23	16.78	12.08	13.72	12.94	13.07	11.67	11.97	12.08	9.84	10.14
Nd	37.22	41.30	41.44	46.07	43.17	41.52	41.14	50.19	53.38	48.40	44.66	34.89	48.54	50.15	49.36	44.45	59.48	40.59	48.11	45.37	45.11	39.98	41.51	41.58	33.75	33.37
Sm	5.31	5.86	5.98	6.61	6.09	6.16	6.11	6.95	7.43	6.38	6.49	4.88	6.78	7.15	6.64	6.14	8.49	5.84	7.09	6.40	6.37	5.67	5.99	5.76	4.75	4.50
Eu	1.46	1.59	1.63	1.65	1.60	1.61	1.65	1.91	2.00	1.83	1.79	1.41	1.66	1.90	1.74	1.62	2.19	1.60	1.91	1.81	1.63	1.54	1.61	1.54	1.41	1.47
Gd	3.46	3.39	3.54	3.80	3.49	3.88	3.70	3.87	4.40	3.50	3.89	2.98	3.89	4.38	3.85	3.49	4.77	3.38	4.09	3.71	3.80	3.31	3.64	3.26	2.79	2.55
Tb	0.44	0.38	0.42	0.45	0.41	0.48	0.44	0.44	0.52	0.40	0.47	0.35	0.46	0.54	0.43	0.40	0.56	0.39	0.49	0.42	0.46	0.40	0.45	0.40	0.34	0.31
Dy	2.25	1.88	2.11	2.16	1.96	2.40	2.21	2.03	2.48	1.82	2.23	1.72	2.22	2.64	2.07	1.88	2.62	1.89	2.40	1.99	2.23	1.87	2.27	1.92	1.63	1.51
Ho	0.42	0.33	0.37	0.37	0.34	0.43	0.40	0.34	0.43	0.30	0.40	0.30	0.39	0.47	0.35	0.31	0.45	0.32	0.40	0.35	0.39	0.31	0.38	0.32	0.29	0.25
Er	1.04	0.79	0.87	0.85	0.79	1.09	0.96	0.80	1.03	0.68	0.94	0.76	0.91	1.19	0.80	0.68	1.06	0.77	1.02	0.83	0.96	0.74	0.94	0.80	0.69	0.59
Tm	0.14	0.11	0.12	0.11	0.11	0.14	0.13	0.10	0.14	0.09	0.13	0.10	0.12	0.16	0.11	0.09	0.14	0.10	0.15	0.11	0.13	0.10	0.13	0.11	0.09	0.08
Yb	0.88	0.63	0.73	0.68	0.63	0.81	0.78	0.60	0.84	0.53	0.77	0.61	0.74	1.01	0.65	0.53	0.84	0.62	0.92	0.71	0.74	0.59	0.77	0.64	0.55	0.49
Lu	0.14	0.09	0.11	0.09	0.09	0.12	0.12	0.09	0.12	0.08	0.12	0.09	0.11	0.15	0.10	0.07	0.13	0.09	0.14	0.10	0.12	0.08	0.11	0.10	0.09	0.07
Ba	2151.00	2287.00	2373.00	2358.00	2522.00	2283.00	2366.00	2592.00	2553.00	2719.00	2340.00	2388.00	2513.00	2516.00	2719.00	2622.00	2937.00	2598.00	2713.00	2695.00	2594.00	2234.00	2283.00	2365.00	2389.00	2591.00
Th	10.52	11.18	10.17	12.32	12.28	11.07	9.75	11.31	11.54	10.21	9.54	9.21	11.14	11.05	12.06	12.96	11.62	12.58	9.47	9.47	11.29	10.63	10.64	9.94	9.16	12.18
Nb	7.53	8.38	7.88	9.47	9.27	9.86	7.06	9.80	12.24	10.66	10.37	7.18	8.35	10.42	9.38	10.80	9.82	10.59	8.03	8.04	8.63	8.81	8.37	6.94	7.28	8.69
Y	11.46	8.86	9.35	9.20	8.67	12.16	10.27	8.73	11.38	7.75	10.53	8.24	10.59	12.53	8.96	7.99	11.82	8.41	10.39	8.89	10.18	8.17	10.43	8.60	7.18	6.64
Hf	3.90	4.04	4.14	4.69	4.64	4.84	3.71	4.50	4.68	4.35	4.38	3.73	4.26	4.17	4.27	4.39	5.17	4.44	4.88	4.92	4.21	4.23	4.16	3.70	3.80	4.23
Ta	0.41	0.47	0.41	0.55	0.52	0.53	0.37	0.47	0.58	0.51	0.51	0.38	0.43	0.57	0.48	0.58	0.50	0.57	0.42	0.42	0.45	0.48	0.47	0.36	0.40	0.45
U	2.20	2.06	1.98	2.09	2.27	2.52	2.03	1.98	2.06	1.97	1.75	1.94	2.44	2.36	2.11	2.20	2.35	2.26	2.18	2.00	2.29	1.78	2.00	2.13	2.04	2.34
Pb	24.24	22.86	19.09	23.81	19.94	23.04	22.22	19.93	21.92	18.11	18.63	22.06	22.56	22.59	26.07	23.49	23.58	24.02	19.77	21.11	25.92	21.00	19.82	23.94	22.64	24.95
Rb	70.60	69.70	65.80	87.70	82.40	81.60	65.20	60.10	50.10	51.40	58.10	60.30	70.00	73.30	67.90	53.90	82.70	77.20	68.50	70.80	67.80	70.40	73.30	77.90	63.90	65.30
Cs	2.00	1.66	1.64	1.35	1.14	1.34	1.31	1.33	1.43	1.01	1.15	1.42	1.68	2.56	1.22	0.38	4.18	2.33	0.99	1.17	1.33	1.10	1.39	1.72	1.88	1.64
Sr	952.00	989.00	1056.00	897.00	952.00	888.00	1065.00	1334.00	1280.00	1193.00	1106.00	991.00	1021.00	1273.00	1033.00	1030.00	1299.00	959.00	1232.00	1212.00	1016.00	931.00	995.00	1203.00	978.00	1040.00
Sc	7.30	6.10	6.50	5.90	6.20	6.00	6.70	6.40	8.60	6.10	7.90	5.80	6.20	8.80	6.20	5.40	8.00	5.50	7.50	7.30	6.00	6.20	6.10	6.40	5.80	5.60
Zr	156.00	158.00	171.00	186.00	187.00	197.00	147.00	190.00	201.00	182.00	181.00	151.00	172.00	169.00	173.00	178.00	208.00	180.00	193.00	194.00	172.00	175.00	168.00	144.00	151.00	174.00

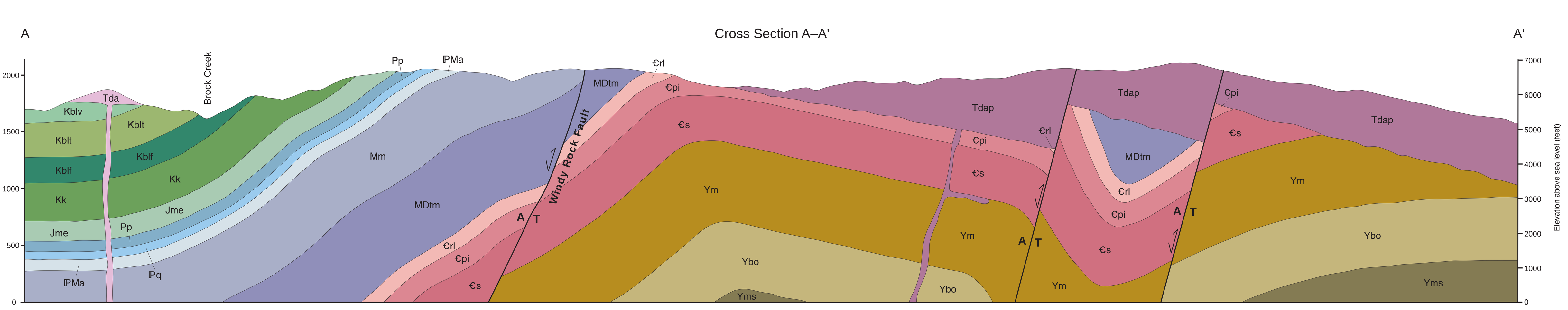
All samples analyzed by X-ray fluorescence (XRF) and inductively coupled plasma mass spectrometry (ICP-MS) at the Washington State University GeoAnalytical Lab. All major elements and trace elements denoted by + were analyzed by XRF, all other trace elements were measured by ICP-MS. FeO* indicates all Fe expressed as Fe_2+. LOI is loss on ignition. Datum used for sample coordinates is World Geodetic Survey 1984 (WGS84).

Table 2. U-Pb zircon ages

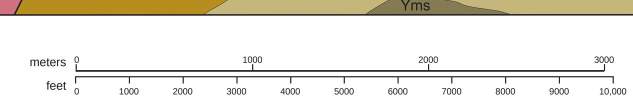
Sample	Map Unit	Latitude	Longitude	Age (Ma)	2σ
ES-07	Tdap	46.7031	-112.7625	46.74	0.27
ES-24	Tdap	46.6597	-112.7748	47.51	0.21
ES-40	Tdap	46.7035	-112.8337	47.12	0.19
ES-47	Tdap	46.7022	-112.8019	46.25	0.27
ES-50	Tdap	46.6841	-112.8087	47.13	0.26
ES-61	Tdap	46.7205	-112.7871	47.10	0.29

Samples analyzed by LA-ICP-MS at the University of California, Santa Barbara. Datum used for sample coordinates is World Geodetic Survey 1984 (WGS84).

Cross Section A–A'



No vertical exaggeration
Surficial units not shown
A/T away from newer / toward newer



UNITS ON CROSS SECTION ONLY

Cs Cambrian, undivided

Yms Mount Shields Formation, undivided

Maps may be obtained from:
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Montana Bureau of Mines and Geology
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GIS production: Paul Thale, MBMG. Map layout: Susan Smith, MBMG.

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Geologic Map of the Windy Rock 7.5' Quadrangle, Powell County, Montana

Jesse G. Mosolf

2016