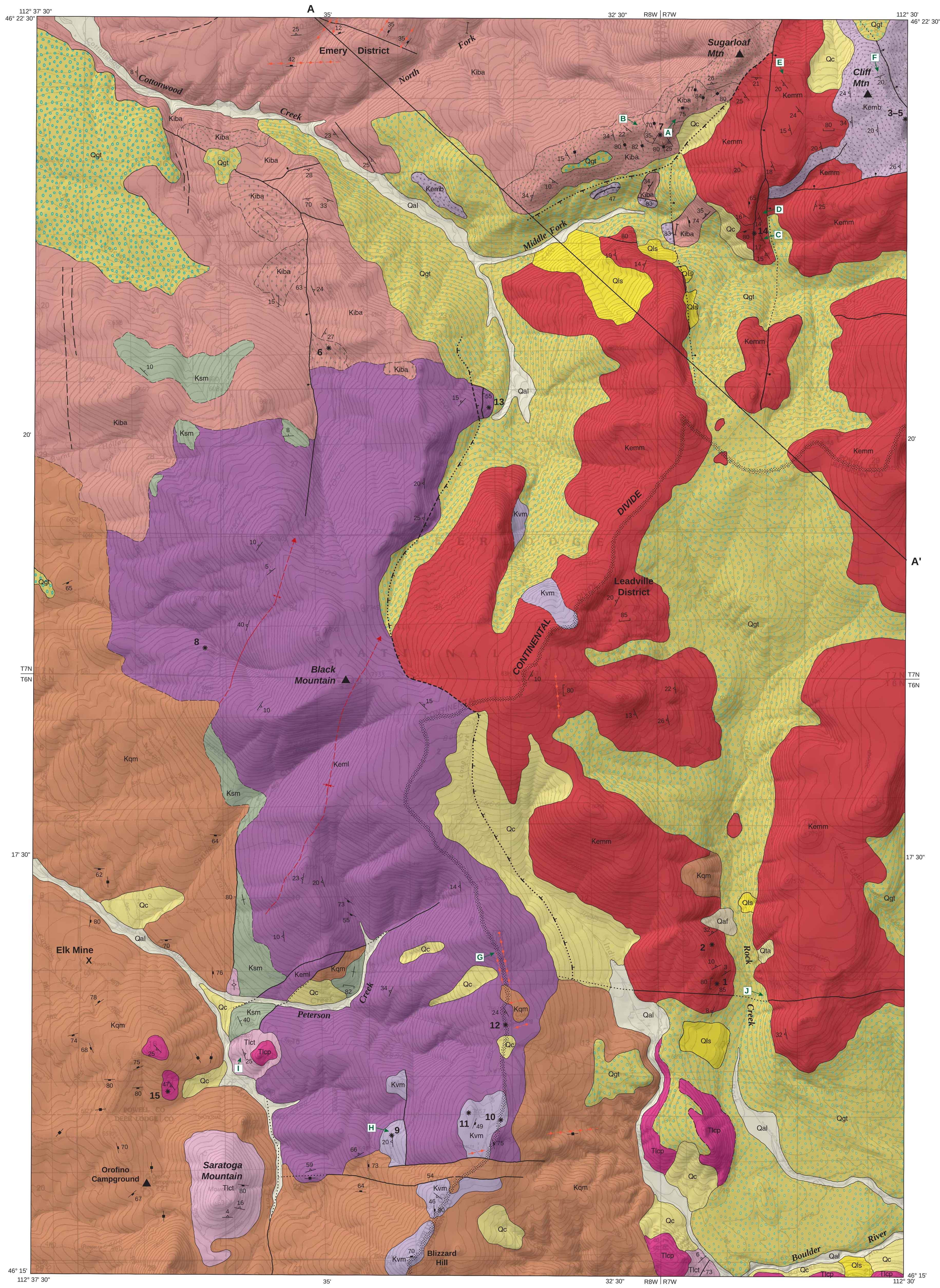
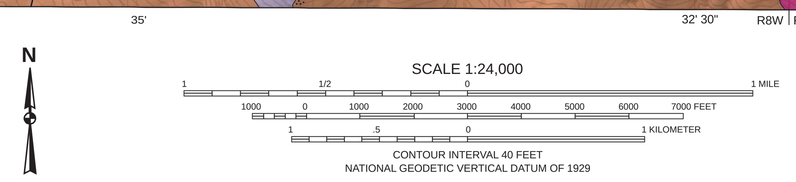


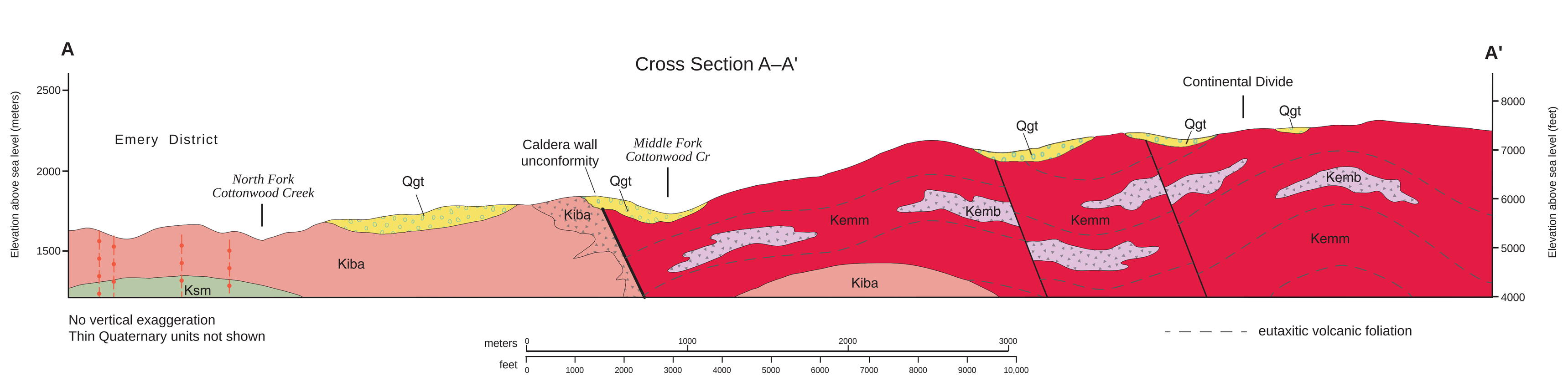
Base map produced by the United States Geological Survey
Control by: USGS, NOS/NOAA and USFS
Compiled from aerial photographs taken 1954–1955
Field checked: 1959
Limited revision from aerial photographs taken 1985
Field checked: 1987 Map edited: 1989
Projection: Lambert Conformal Conic
Grid: 1000 meter Universal Transverse Mercator Zone 12
UTM grid declination: 1° 08' 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.



CONTOUR INTERVAL 40 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

Maps may be obtained from:
Publications Office
Montana Bureau of Mines and Geology
1300 West Park Street
Butte, Montana 59701-8997
Phone: (406) 496-4174 Fax: (406) 496-4451
http://www.mbmg.mtech.edu

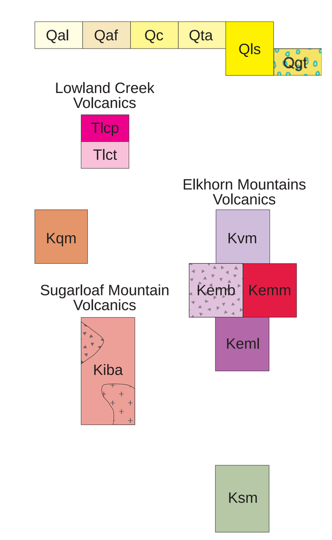


No vertical exaggeration
Thin Quaternary units not shown

Research supported by the U.S. Geological Survey, National Cooperative Geologic Mapping Program, under USGS award number G13AC00210. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.

GIS production: Yiwen Li and Paul Thale, MBMG. Map layout: Susan Smith, MBMG.

CORRELATION DIAGRAM



MAP SYMBOLS

Contact: dashed where approximately located.

Fault: dashed where approximately located, dotted where concealed, dip indicated where known.

Normal fault: dashed where approximately located, dotted where concealed, bar and ball on downthrown side, dip indicated where known.

Plunging syncline axial trace: dashed where approximately located.

Plunging anticline axial trace: dashed where approximately located.

Quartz and/or sulfide-bearing mineral vein.

Caldera wall unconformity: dashed where approximately located; dotted where concealed.

Continental Divide.

Strike and dip of inclined eutaxitic volcanic foliation.

Strike of vertical eutaxitic volcanic foliation.

Strike and dip of inclined bedding.

Strike of vertical bedding.

Strike and dip of inclined joint.

Strike of vertical joint.

Strike and dip of inclined cleavage.

Strike of vertical cleavage.

Sample location.

Photo location. Arrow points in direction of view.

INTRODUCTION AND PREVIOUS MAPPING

The Sugarloaf Mountain 7.5' quadrangle is ~15 miles southeast of Deer Lodge and straddles the Continental Divide. Greater than 80 percent of the quadrangle is part of the Beaverhead–Deerlodge National Forest. Ruppel (1961) and Derkey and others (2004) mapped the quadrangle at a scale of 1:48,000, incorporating 1:24,000-scale mapping by Watson (1986). Derkey (1986, 1987) conducted large-scale mapping of mining districts and prospects in the quadrangle.

ECONOMIC GEOLOGY

The Emery District was the main producer of silver, lead, and zinc ores (Pardee and Schrader, 1933) and by the 1950s had produced ore valued at more than $2,000,000 (Robertson, 1953). Derkey (1987) described zones of sericite and low-grade gold–silver mineralization at the Elk Mine, located in the southwest quarter of the quadrangle. Low-grade gold and silver ores occur in the central part of the map (Federspiel and Mayerle, 1988). Exploration geologists described sulfide mineralization in float rock on the west slope of Black Mountain, at 2,700 m (6,800 ft) (unpublished data, MBMG Mining Archives, 2014). Sulfide minerals occur in float rock at the head of Peterson Creek, and at the same altitude as observed at Black Mountain (this study).

GEOLOGIC SUMMARY

Widespread magmatism and deformation occurred throughout southwestern Montana during the Late Cretaceous–Eocene (Laramide) (Tilling and others, 1968). The Late Cretaceous Elkhorn Mountains Volcanics (EMV) are magmas erupted from, and then later intruded by, the Boulder Batholith (Lipman, 1984; Rutland and others, 1989). Kalakay and others (2001) suggested thrust faults guided emplacement of batholith rocks into the crust, as well as into the EMV.
Late Cretaceous andesite intrusions (fig. 1A), breccia (fig. 1B), and lavas occur near Sugarloaf Mountain in the northeastern quarter of the quadrangle. These intrusions (unit Kiba) are trace relics of a 5-km-long volcanic fissure. South of Cottonwood Creek another cluster of intrusions extends northwest for 5 km, paralleling the creek. Further south, Kiba merges with andesitic lavas and isolated trachydacite intrusions mapped by Derkey and others (2004) as lower member EMV (Keml). Collectively these volcanic units (Kiba and Keml) overlie Cretaceous metasedimentary rocks (Kms), are likely age-equivalent, and are remnants of dissected stratovolcanoes.

The middle member of the EMV overlies the andesitic rock units (Kiba and Keml). Bedded basaltic andesite (table 1, fig. 2, sample 14) accretionary lapilli (fig. 1C) grade upward to conglomeratic lahar deposits (fig. 1D) and form the base of the unit. These volcanogenic sediments record erosion of nearby andesitic cones prior to eruption of hundreds of meters of welded rhyolite ignimbrite (fig. 1E, unit Kemm).

Clast-supported breccia (fig. 1F, unit Kemb) is interstratified with ignimbrite. In the northeast corner of the quadrangle, at Cliff Mountain, angular breccia clasts are several tens of meters across. These massive breccia deposits probably formed during vent floor collapse. Middle member ignimbrites and interstratified breccia (units Kemm and Kemb) are in contact with andesitic rocks (Kiba and Keml) along a curved, 16-km-long boundary that represents a caldera-wall unconformity within rocks of the older andesite stratovolcanoes.
Keml is gently folded and fold axes plunge 15° towards northeast near its contact with batholithic rocks (Kqm). Quartz veins (fig. 1G) cut Keml and the rock is recrystallized to hornfels (unit Kvm, fig. 1H) along the Continental Divide in the southern part of the quadrangle. A 0.25 km^2 EMV roof pendant (Kvm) crops out near Blizzard Hill. Faulted Cretaceous metasedimentary beds are vertically oriented north of Peterson Creek, and sandwiched between EMV and batholithic rocks. All together, these observations suggest southwest to northeast compression, high-angle faulting, and contact metamorphism of the EMV and older Cretaceous sediments, which is consistent with the model for batholith emplacement proposed by Kalakay and others (2011).

Eocene volcanic rocks crop out in the southern part of the quadrangle. They are well exposed at Saratoga Mountain where white, bedded, crystal- and lithic-rich tuff (unit Tlct, fig. 1I) has similar texture and mineralogy to the 53.0 Ma (^{40}Ar-^{39}Ar on biotite, Dudas and others, 2010) basal tuff of the Lowland Creek volcanics (Smedes, 1962; Smedes and Thomas, 1965). Maroon, porphyry rhyodacite overlies Tlct and may correlate with 51.8 Ma (^{40}Ar-^{39}Ar on biotite, Dudas and others, 2010) rhyodacite of the Lowland Creek volcanic field.

The distribution of middle and late Pleistocene glacial till (Qgt) suggests that alpine glaciers were present in ancestral drainages of Cottonwood Creek and Rock Creek (Derkey and others, 2004).

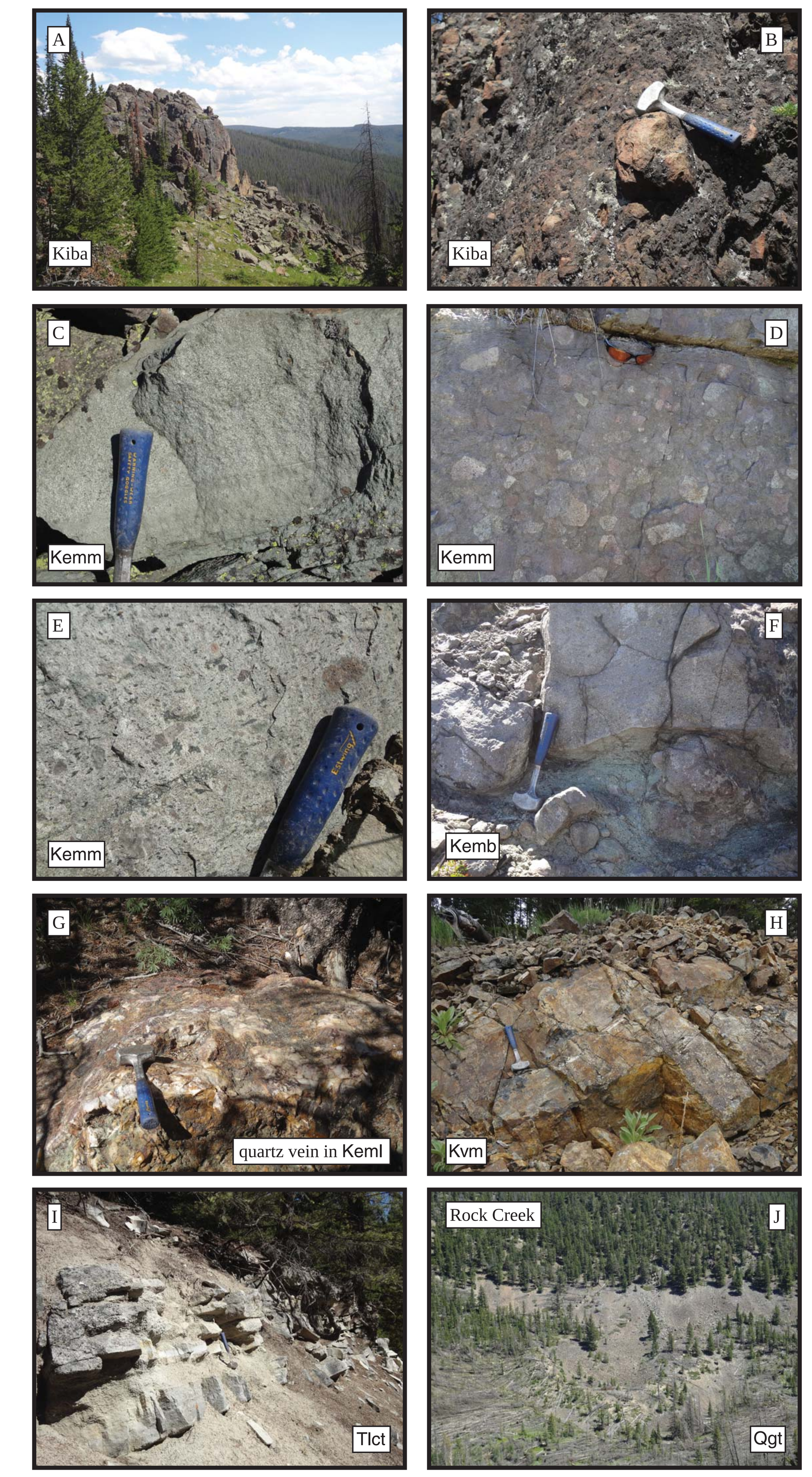


Figure 1. Photographs of major rock units shown on map and discussed in text.

DESCRIPTION OF MAP UNITS

Sediments

Qal **Alluvium (Holocene)—**Well-sorted gravel, sand, silt, and clay along modern streams and floodplains. The unit is less than 3 m (10 ft) thick.

Qaf **Alluvial fan (Holocene)—**Alluvium deposited by streams that issue from narrow channels. An abrupt change in topographic gradient creates downgradient fanning morphology. Thickness undetermined.

Qc **Colluvium (Holocene)—**Loose cobbles and pebbles within soils with undeveloped profiles. The material has experienced limited transport and may include talus and cliff debris. Thickness undetermined.

Qta **Talus slope debris (Holocene)—**Rock fragments, usually coarse and angular, found at the base of cliffs and steep slopes from which they are derived.

Qls **Landslide deposit (Holocene)—**Mass wasting deposits of clay- to boulder-size sediment. Includes rotated or slumped blocks of bedrock and surficial sediment, soils, and mudflow deposits. Thickness undetermined.

Qgt **Glacial till deposits (Middle and Late Pleistocene)—**Unconsolidated, poorly sorted rock and soil deposits that contain subangular to rounded, cobble- to boulder-size clasts in a grayish brown, clay-rich matrix. Clasts consist primarily of Cretaceous and Tertiary igneous rocks. The till formed during the Bull Lake and Pinedale glaciations of the Rocky Mountains (see Derkey and others, 2004 for complete summary). Includes outwash gravels and small, < 1 km^2 (0.4 mi^2) rock glacier moraines (fig. 1J) that occur at 2,080–2,130 m (6,820–7,000 ft) above mean sea level. Rock glacier moraines appear as masses of angular boulders that once had ice cores and formed adjacent to steep cliffs.

Lowland Creek Volcanics (Eocene)

Tlcp **Welded porphyry rhyolite ash-flow tuff—**Massive, blocky and platy, maroon outcrops. Rock contains over 50 percent phenocrysts that include plagioclase, quartz, and biotite, along with sparse hornblende and pyroxene. Crystals are fragmented and set in a devitrified groundmass devoid of lithic clasts. Good exposure of the rhyolite tuff (table 1, fig. 2, sample 15) occurs south of the Boulder River in the extreme southeastern corner of the quadrangle. The unit correlates with unit Trdp of Derkey and Bartholomew (1988) and perhaps with a 51.8 Ma (^{40}Ar-^{39}Ar on biotite, Dudas and others, 2010) rhyodacite of the Lowland Creek volcanic field. Derkey and others (2004) described a basal vitrophyre up to 5 m (16 ft) thick and estimated a total thickness of 65–95 m (213–312 ft) for the unit.

Tlct **Lithic-bearing rhyolite ash-flow tuff—**Unconsolidated to poorly welded, white and gray pumice and lithic-rich air-fall tuff. The tuff is weakly stratified to bedded. Includes beds of crystal-rich, gray, welded porphyry ash-flow tuff (fig. 1I). The occurrence of lithic clasts in the tuff and abundant biotite distinguishes the unit from Tlcp. Air-fall tuff in the southeastern corner of the quadrangle has a "popcorn" texture that may represent a paleosol. In part, the unit correlates with unit Trt of Derkey and Bartholomew (1988). Cross-bedded, water-laid deposits (unit Tlct) described by Derkey and others (2004) may be a surge deposit facies of the unit. The tuff has texture and mineralogy similar to the 53.0 Ma (^{40}Ar-^{39}Ar on biotite, Dudas and others, 2010) basal tuff of the Lowland Creek volcanic field. The rhyolite tuff is 120 m (394 ft) thick.

Cretaceous Igneous Rocks

Kqm **Granitic plutons—**The unit is primarily the Butte granite, the principal pluton by volume of the Boulder Batholith. May include small masses of other plutons. Minerals include normal-zoned plagioclase (45–50 percent), orthoclase (20–30 percent), and quartz (5–10 percent) (Berg and Hargrave, 2004). Lund and others (2002) dated the Butte granite at 74.5 Ma (U-Pb on zircon). Aplite dikes and sills crosscut the unit throughout the exposure.

Kvm **Volcanic rocks, thermally metamorphosed—**Deformed and metamorphosed basaltic andesite–dacite (table 1, fig. 2, samples 9, 10, and 11). These volcanic rocks occur as recrystallized EMV, or roof pendants over granitic plutons (Kqm). Kiba or Keml is the likely protolith. The rock is recrystallized to dense, black hornfels (fig. 1H) locally. The hornfels texture varies among vesicular, glassy, and aphanitic. Coarse crystalline varieties have gabbro mineralogy and the texture may reflect slow recrystallization of the volcanic protolith during metamorphism. Good exposures occur along and west of the Continental Divide. Thickness undetermined.

Kiba **Basaltic andesite–andesite intrusions (cross pattern), breccia (triangle pattern), and lavas related to the Elkhorn Mountains Volcanics—**These rocks are likely age-equivalent to the lower member of the Elkhorn Mountains Volcanics. Derkey and others (2004) described three types of lavas based on differences in mineralogy: (1) dark gray basalt with 5–7-mm plagioclase phenocrysts, (2) medium to dark green mafic rock with 1–3 mm augite phenocrysts in a sugary matrix, and (3) basalt with centimeter-long augite phenocrysts set in a dark green matrix. Semi-aligned rock towers (fig. 1A) crop out in the northeastern map corner near Sugarloaf Mountain, and are accessible via a Forest Service pack trail. The rock towers are intrusions that formed along a volcanic fissure, since deeply eroded. Medium to dark green porphyritic basaltic trachyandesite intrusions (table 1, fig. 2, sample 6) crop out south of Cottonwood Creek. The intrusions contain 1–3 mm augite phenocrysts and correlate with unit Kbpy of Derkey and others (2004). Most intrusions are surrounded by breccia. Good exposure of breccia occurs along the ridge trending northeast to Sugarloaf Mountain (see map). Breccia surrounds intrusive rock towers near Sugarloaf Mountain and is monolithologic, red to brown, boulder-sized, sub-angular blocks of basaltic andesite (table 1, fig. 2, sample 7). The blocks are encased in dark red to brown agglomerate matrix (fig. 1B). Exposed breccia thickness is 30 m (98 ft). Lava flows, by volume, comprise most of the unit and host ore deposits in the Emery District. The lavas are dark gray and green, fine-grained, and sometimes amygdaloidal. Some lavas are vesicular and contain red, oxidized, autobreccia zones. Ruppel (1961) described conspicuous rounded plagioclase phenocrysts 1–4 mm long in some of the lavas. The unit is at least 200 m (656 ft) thick.

Elkhorn Mountains Volcanics (Late Cretaceous)

Middle Member

Kemb **Ash-flow tuff breccia and debris flows—**Blocks of angular to subangular tuff, welded tuff, and dioritic intrusive rocks in a fine ash matrix. The unit in part correlates with unit Kvp of Ruppel (1963). Clast-supported breccia (fig. 1F) occurs at Cliff Mountain in the northeast corner of the map. The breccia clasts are mixed compositions (table 1, fig. 2, samples 3, 4, and 5). Blocks of andesite, related intrusions, and metasedimentary rocks (units Kiba, Keml, and Kms) occur as breccia clasts. Some blocks are as large as 10–30 m wide at Cliff Mountain. The unit is up to 400 m (1,312 ft) thick.

Kemm **Welded ignimbrite—**Medium to dark gray ignimbrite that contains abundant plagioclase and lithic clasts. The unit appears to record more than one pulse of rhyolitic (table 1, fig. 2, samples 1 and 2) volcanism. Outcrops are massive and cliff forming. Fine-grained ash-flow tuff has 0.5–2.0 mm plagioclase phenocysts. The tuff contains fiamme and vitroclasts that are commonly 1–5 cm long (fig. 1E) on the west side of Rock Creek, located in the southeastern corner of the quadrangle. The base of the tuff crops out near the head of the middle fork of Cottonwood Creek, located in the northeastern corner of the quadrangle. Here ~20 m of coarse-bedded basaltic-andesite (table 1, fig. 2, sample 14) accretionary lapilli (fig. 1C) grade upwards to conglomerate beds (fig. 1D). Maroon vitrophyre ~15 m thick occurs southeast of Sugarloaf Mountain, located in the northeastern corner of the quadrangle, and grades upwards to gray and buff welded tuff. The tuff contains pebble-sized porphyritic volcanic rocks, granitoids, and metasedimentary rocks. South of Sugarloaf Mountain and near the middle fork of Cottonwood Creek 50 m of the section is exposed. The ash-flow tuff, in part, correlates with unit Kvt of Ruppel (1963) and has a total thickness of ~900 m (2,953 ft).

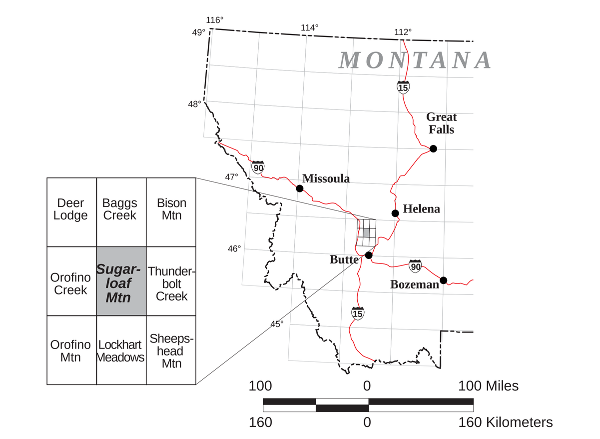
Lower Member

Keml **Andesite lavas, breccia, and related intrusions—**Andesite (table 1, fig. 2, samples 8, 12) exhibits vesicular, amygdaloidal, glassy, aphanitic, and porphyritic texture. Plagioclase and pyroxene phenocrysts occur in both fine and coarse textures. The unit also includes small porphyritic trachydacite intrusions (table 1, fig. 2, sample 13). A trachydacite intrusion crops out along the Forest Service road south of Cottonwood Creek (see map, sample 13 location). Here, hydrothermal fluids brecciated the intrusion and introduced sulfide minerals into the groundmass. The trachydacite contains 4-mm-long clusters of plagioclase and 1–2 mm hornblende phenocrysts. Keml is at least 200 m (656 ft) thick.

Cretaceous Metasedimentary Rocks

Ksm **Sedimentary rocks, metamorphosed (Late and Early Cretaceous)—**Light tan to gray, silicified and dense, amorphous to aphanitic metamorphic rock. Includes contact metamorphosed silicic tuff that resembles chert described by Derkey and others (2004). Good exposures occur along a north–south trend, near the contact between andesite lavas (Keml) and granitic plutons (Kqm), 1.6 km (1.0 mi) east of the Elk Mine in the southwestern corner of the quadrangle. Here, relict bedding is observed in the metamorphic rock. The protolith was likely siliceous mudstone and sandstone of the middle siliceous unit of the Colorado Group (Ruppel, 1963) – equivalent to the Frontier and Mowry Formations described by Vuke (2011). The unit approaches 120 m (394 ft) in total thickness.

LOCATION MAP



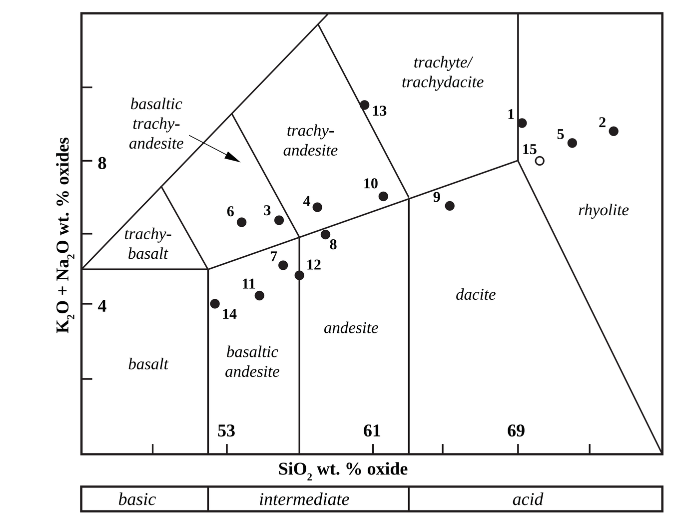


Figure 2. Late Cretaceous (black circles) and Eocene (open circles) igneous rock compositions. Chemical classification after Le Bas and others (1986). Note that oxide data shown are normalized to 100% volatile free. For example (see table 1, #1): raw data for SiO_2 = 67.96. Normalized data for SiO_2 = 67.96 x (100/a.t.) = 69.03.

Table 1. Raw geochemical data for Late Cretaceous and Eocene igneous rocks. Sample locations shown on the map.

#	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
sample ID	KCS-13-43	KCS-13-44	KCS-13-78a	KCS-13-78a	KCS-13-78a	KCS-13-18	KCS-13-47	KCS-13-16	KCS-13-06	KCS-13-37	KCS-13-38	KCS-13-35	KCS-13-25a	KCS-13-45	KCS-13-40	*error (%)*
map unit	Kemm	Kemm	Kemb (c_1)	Kemb (c_2)	Kemb (c_3)	Kiba (i)	Kiba (i)	Keml	Kvm	Kvm	Kvm	Keml	Keml (i)	Kemm	Tlcp	
XRF (wt. %)																
SiO_2	67.96	73.78	54.34	56.24	69.19	49.55	55.84	57.83	63.71	59.99	53.70	56.33	58.62	52.07	69.23	*0.64*
TiO_2	0.52	0.30	0.97	0.92	0.48	0.86	1.10	1.04	0.58	0.92	0.87	1.05	1.01	0.91	0.34	*0.54*
Al_2O_3	15.49	13.85	16.86	16.09	12.23	14.60	16.80	18.31	16.00	16.88	15.19	15.62	16.94	13.98	15.30	*0.37*
*FeO_{Total}	3.03	1.13	7.84	7.93	1.97	8.03	8.32	6.95	4.42	5.40	8.44	8.91	4.77	8.38	2.19	*2.09*
MnO	0.04	0.05	0.14	0.15	0.09	0.23	0.17	0.14	0.10	0.12	0.18	0.18	0.06	0.19	0.02	*0.22*
MgO	0.62	0.35	3.14	2.83	0.33	7.84	3.78	2.04	1.86	2.30	5.53	5.27	2.01	4.23	0.88	*0.71*
CaO	1.93	0.75	7.17	6.14	3.80	5.33	7.24	6.45	4.48	5.42	9.42	6.77	3.61	7.80	2.25	*0.71*
Na_2O	3.69	3.02	2.99	3.85	3.28	2.03	2.77	3.44	3.11	3.37	1.26	2.40	3.05	2.28	4.16	*0.75*
K_2O	5.02	5.51	3.16	2.59	4.59	3.70	2.22	2.44	3.39	3.36	2.71	2.22	6.17	1.87	3.63	*0.59*
P_2O_5	0.13	0.03	0.36	0.35	0.12	0.44	0.35	0.30	0.23	0.32	0.30	0.29	0.59	0.39	0.11	*0.90*
LOI	0.79	0.85	2.32	2.43	2.85	6.41	1.06	0.30	1.52	1.00	0.88	0.05	1.60	7.46	1.05	
a.t.	98.45	98.78	96.96	97.09	96.08	92.60	98.60	98.93	97.89	98.07	97.60	99.04	96.84	92.09	98.11	
Trace elements (ppm) (XRF)																
Ni	1	0	7	9	1	207	3	2	10	8	15	10	8	8	15	*0.6*
Cr	5	4	34	35	4	402	31	4	38	26	78	65	3	45	30	*1.4*
Sc	9	5	21	20	6	19	24	17	11	14	28	28	10	25	4	*13.7*
V	23	13	191	170	37	180	217	140	88	114	210	225	217	194	30	*1.9*
Ba	1983	1380	893	1013	2257	922	759	800	1158	953	913	749	1527	636	1221	*1.0*
Rb	116	151	64	54	74	92	53	73	88	103	87	66	156	49	107	*0.3*
Sr	548	213	759	738	420	544	679	488	616	728	862	621	988	430	571	*0.4*
Zr	259	214	163	162	213	138	164	215	215	184	153	193	259	187	139	*0.6*
Y	32	30	24	23	23	20	24	32	26	23	24	27	23	28	9	*1.9*
Nb	15	16	10	10	15	9	10	12	11	12	9	12	16	11	10	*7.1*
Ga	13	14	19	16	7	16	19	20	19	19	19	19	18	17	21	*1.0*
Cu	2	0	26	28	4	36	11	5	7	29	31	14	212	8	8	*2.2*
Zn	21	25	95	87	30	309	111	99	72	74	105	115	14	99	55	*3.2*
Pb	9	24	13	11	14	64	10	13	16	14	12	11	8	25	27	*1.7*
La	45	43	33	36	40	23	30	35	41	39	33	35	43	46	33	*5.8*
Ce	87	87	68	68	73	52	65	76	70	74	60	70	78	82	51	*0.5*
Th	13	17	8	8	12	7	6	9	10	10	8	9	13	9	10	*17.3*
Nd	33	33	31	31	31	25	30	35	31	31	31	32	31	38	21	*9.6*
U	3	4	1	3	3	1	1	1	2	3	2	3	4	3	3	*51.2*

Analysis performed by X-Ray Fluorescence (XRF) at Washington State University. *All Fe expressed as Fe^{2+}; c = clast with subsample indicated; i = intrusion; LOI = loss on ignition; a.t. = analytical total.
Error calculated from duplicate sample runs.

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Geologic Map of the Sugarloaf Mountain 7.5' Quadrangle, Deer Lodge, Powell, and Jefferson Counties, Montana

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