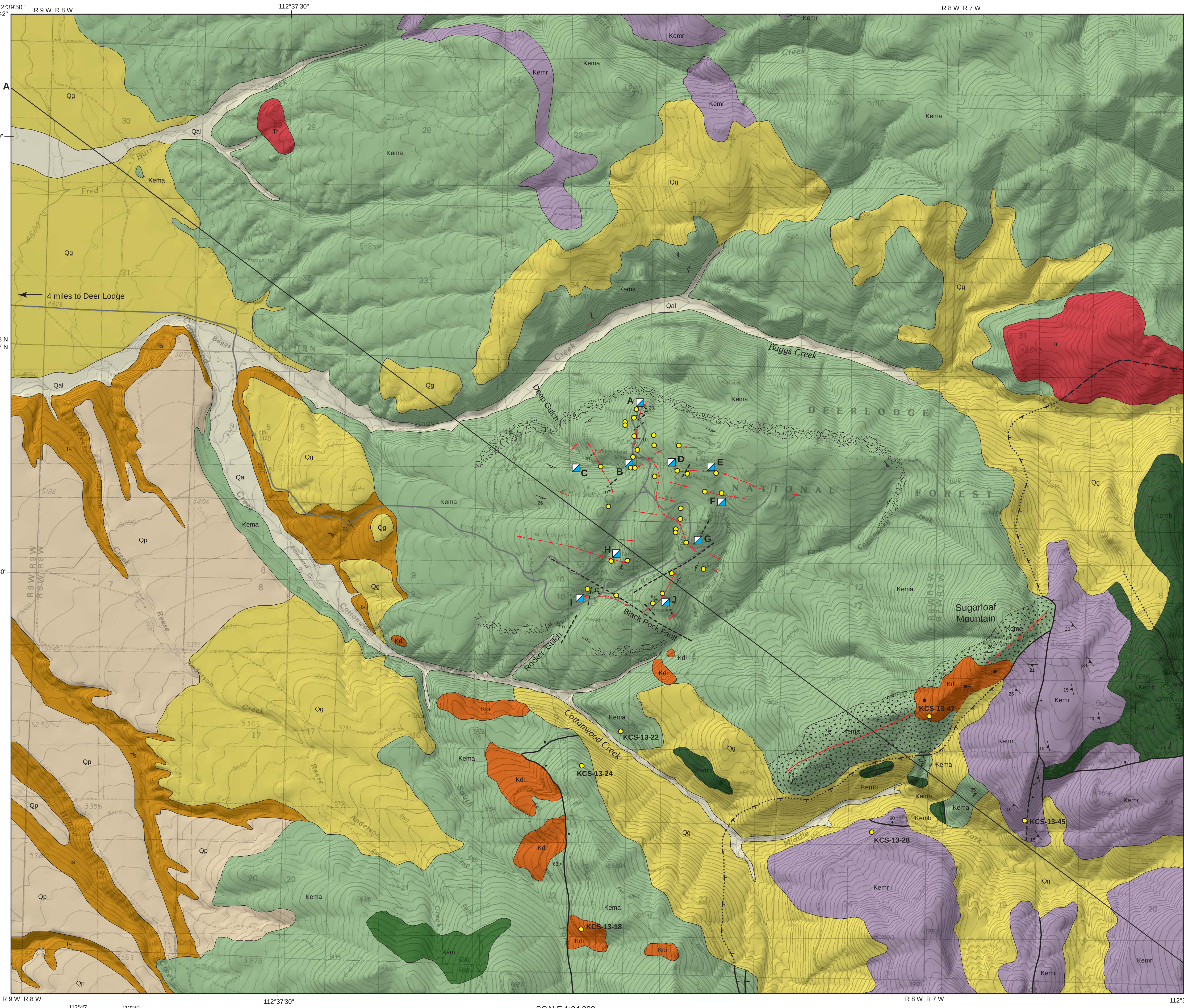

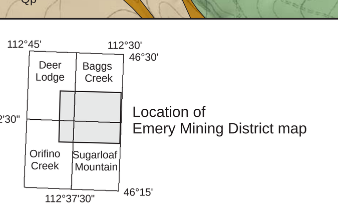

SCALE 1:24,000

CONTOUR INTERVAL 40 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

Maps may be obtained from:
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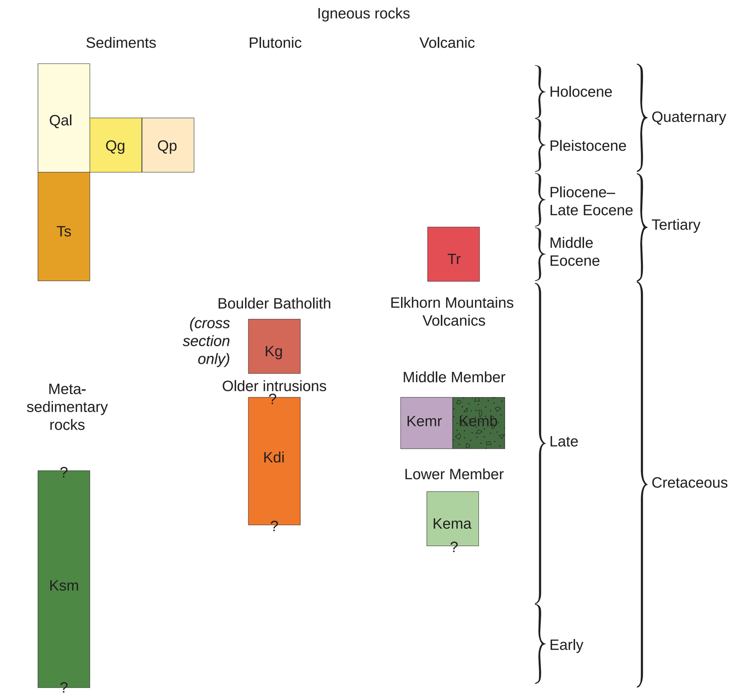
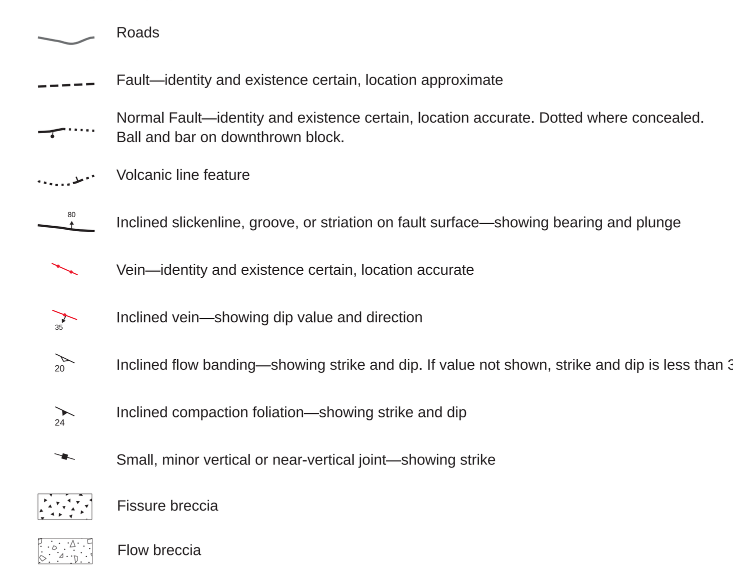
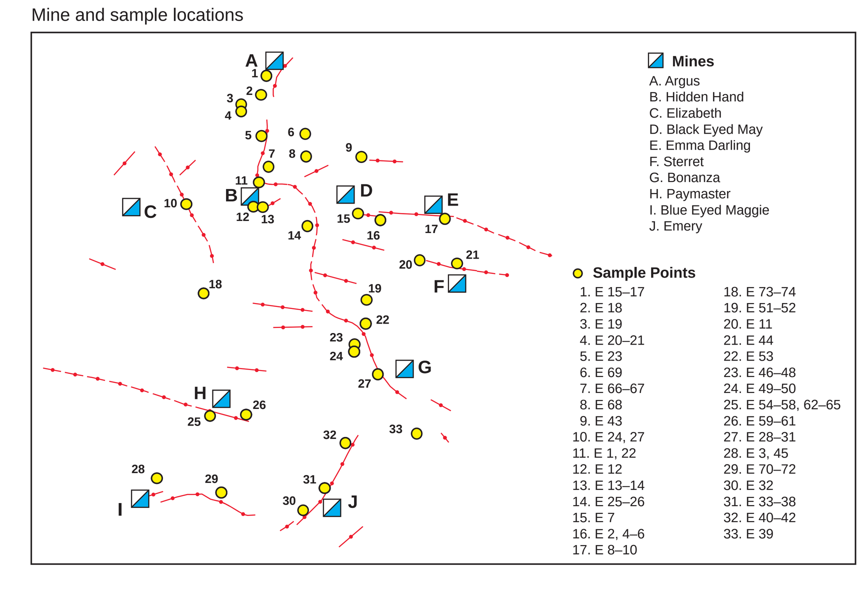
CORRELATION DIAGRAM



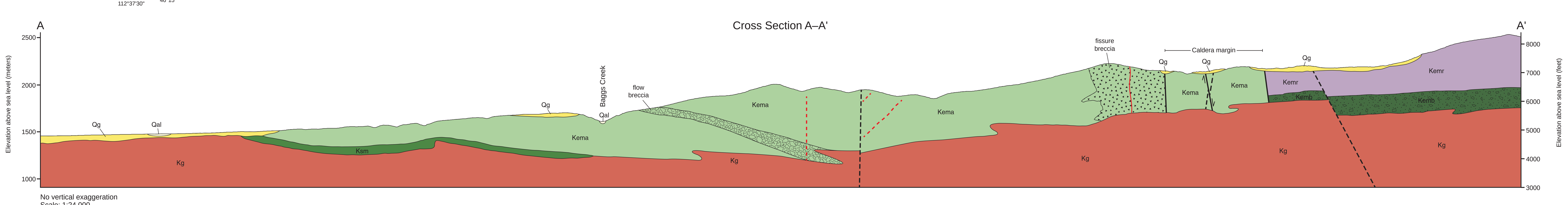
MAP SYMBOLS



Mine and sample locations



Cross Section A–A'



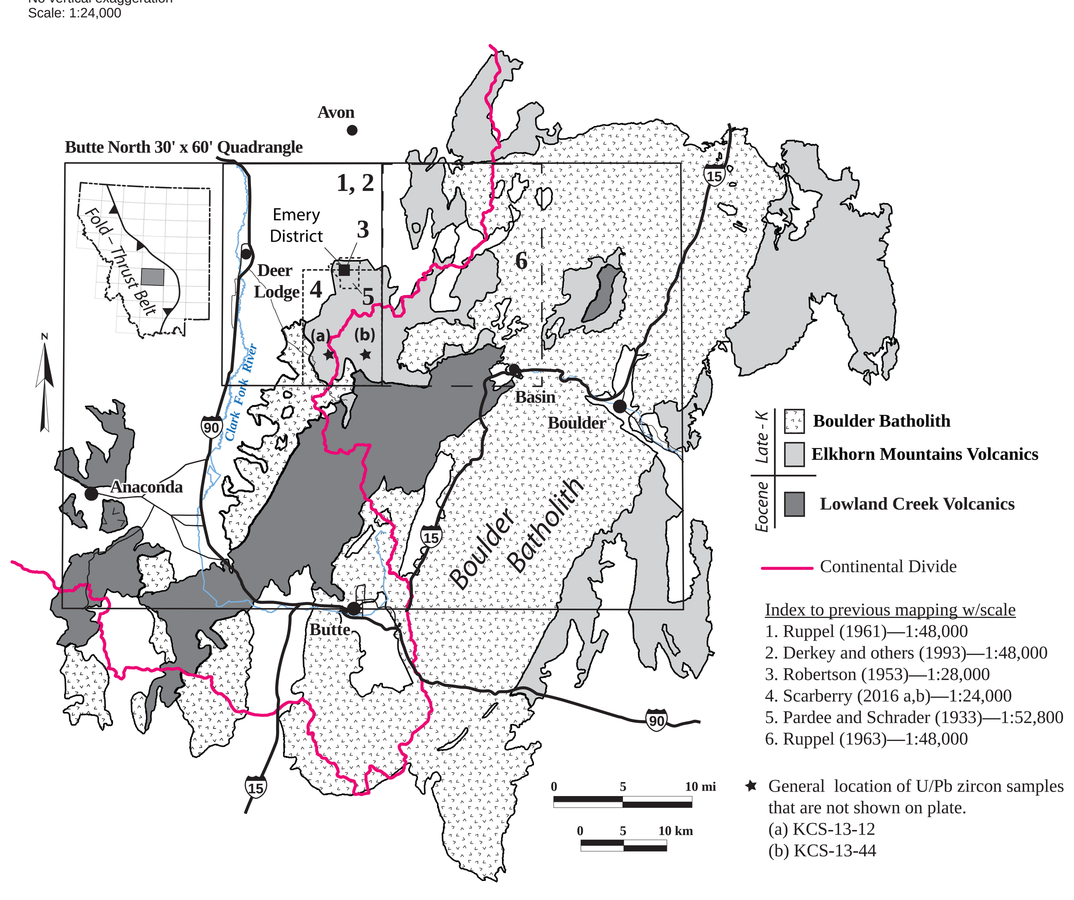


Figure 1. Index to existing geologic mapping along the northwest flank of the Boulder Batholith. Geology after Vuke and others (2007).

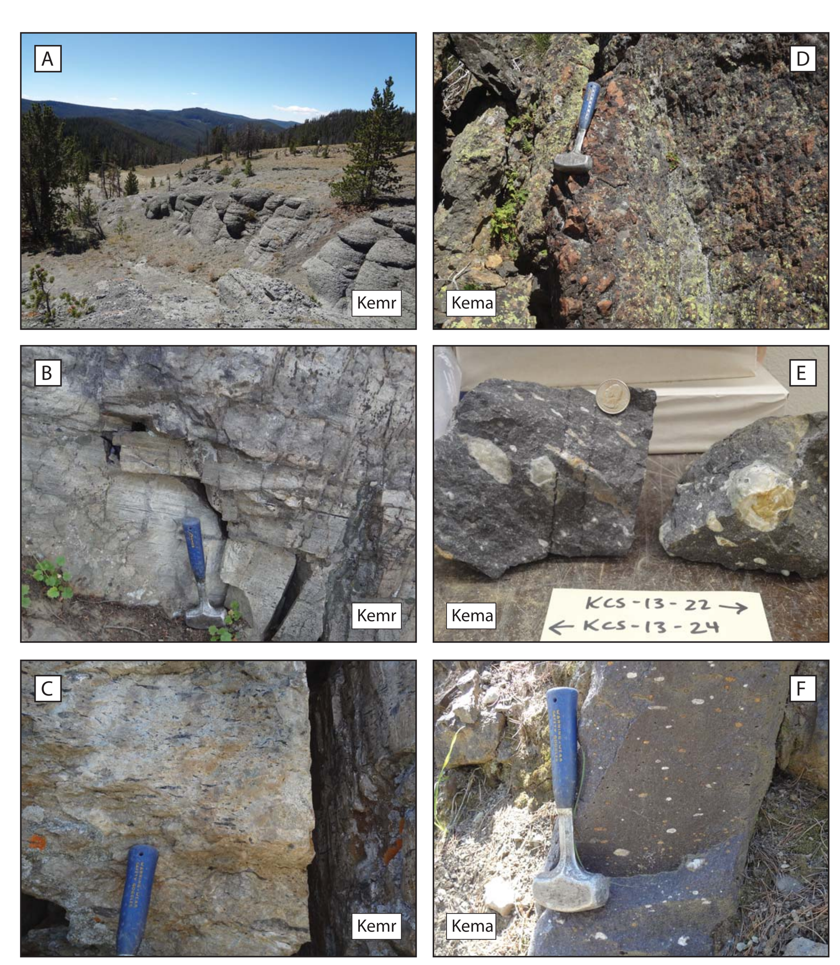


Figure 2. (A) Glacial scour channel in ignimbrite near the top of the Kemr sequence located less than half a kilometer east of Sugarloaf Mountain. (B) Flattened pumice near the center of the Kemr sequence south of Sugarloaf Mountain. Note the width to length ratio of the flattened pumice is approximately 1:100. (C) Less compacted, wispy pumice fragments, or fiamme, towards the top of the Kemr sequence east of Sugarloaf Mountain. (D) Fissure breccia in the Kema sequence southwest of Sugarloaf Mountain. (E) Hand specimen of large, irregularly shaped amygdules, from the Kema sequence. (F) Almond-shaped amygdules in outcrop from the Kema sequence.

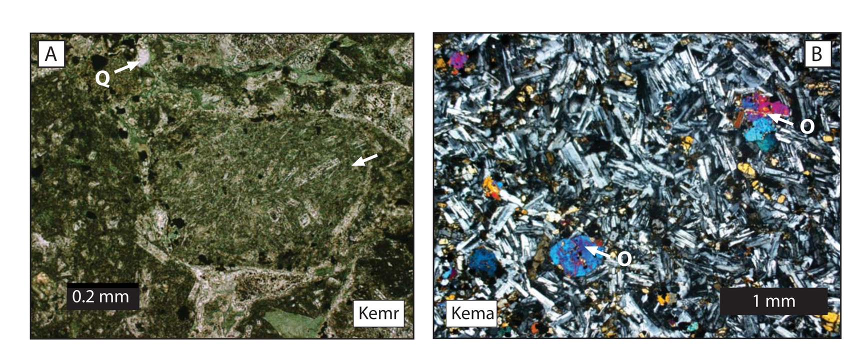


Figure 3. (A) Photomicrograph of volcanogenic sandstone from the base of the Kemr sequence (sample KCS-13-45, see map). The larger particles exhibit trachytic texture (arrow) and were originally basaltic. They are subrounded to subangular and may have been produced, in part, by fluvial reworking. Mixing with mud and scarce non-volcanic quartz grains (Q) likely occurred during mass-flow resedimentation. Note extensive chlorite alteration (green) of both clasts and matrix. Plane polarized light. (B) Photomicrograph of breccia clast from the fissure breccia sequence (Kema) southwest of Sugarloaf Mountain (sample KCS-13-47, see map). Breccia clast is porphyritic olivine (O) basalt from the Keba sequence. Cross polarized light.

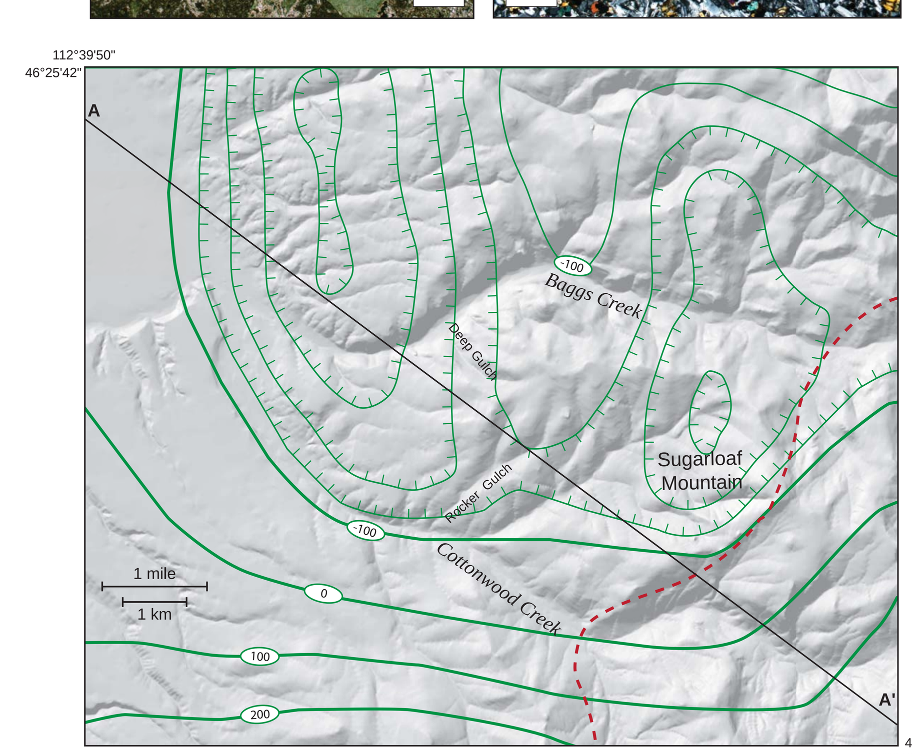


Figure 4. Aeromagnetic anomaly map reduced to the pole (north). Contour interval (solid line) is 100nt (nanoteslas). Contour interval (hatchured line) is -10nt. From Hanna and others (1994). Proposed caldera margin of Scarberry (2016a) shown as a dashed red line.

INTRODUCTION

The Elkhorn Mountains Volcanics (EMV) and Boulder Batholith record Mesozoic magmatism concurrent with fold–thrust belt shortening in southwestern Montana (fig. 1); (Rutland and others, 1989; Lageson and others, 2001). Batholith rocks intrude their volcanic carapace, the EMV, and together provide an uncommon exposure of a continental magma system (e.g., Lipman, 1984). The Emery mining district lies on the northwest flank of the Boulder Batholith (fig. 1), where precious metal ore deposits occur in high- and low-angle polymetallic vein systems hosted by EMV basalt–andesite lavas.

Previous Mapping

Observations from six studies (fig. 1) are used in the current map compilation. Pardee and Schrader (1933) published a geologic map of the Emery mining district that showed the prominent veins, mines, and prospects in Late Cretaceous basalt–andesite lavas. Robertson (1953) added complete mineralogical descriptions of the basalt–andesite lava sequence and mapped lava flow breccia, faults, veins, mines, and mine workings in greater detail. Ruppel (1961) conducted reconnaissance mapping of the Deer Lodge 15' quadrangle and Ruppel (1963) also produced a map of the adjacent Basin 15' quadrangle (fig. 1). Derkey and others (1993) mapped and compiled the Deer Lodge 15' quadrangle and focused on Tertiary–Quaternary sediments. Scarberry (2016a) mapped the Sugarloaf Mountain 7.5' quadrangle and divided EMV igneous sequences based on their proximity to source vents.

UNIT DESCRIPTIONS

Sediments

Qal **Alluvium (Holocene–Pleistocene)**—Well-sorted gravel, sand, silt, and clay along modern streams and floodplains. Includes fan deposits adjacent to stream channels, talus slope debris, colluvium, and landslides. Thickness is variable but less than 10 m.

Qp **Pediment surfaces (Pleistocene)**—Grain-supported, 1 to 3-m thick layers of sediment that are not well exposed. The sediment layers are poorly to moderately stratified and sorted, and unconsolidated. Derkey and others (1993) described three pediment surfaces above the modern river level (oldest to youngest): (1) subrounded to rounded, cobble- to boulder-size clasts that occur 165–260 m above the modern river level; (2) subrounded to rounded, boulder-, cobble-, and pebble-size clasts that occur 135–200 m above the modern river level, and (3) boulder-, cobble-, and pebble-size clasts that occur 24–35 m above the modern river level.

Qg **Glacial deposits (Pleistocene)**—Till and outwash gravels formed during the Bull Lake and Pinedale glaciations of the Rocky Mountains (Derkey and others, 1993). Till is not stratified, unconsolidated, and poorly sorted rock and soil deposits that contain subangular to rounded, cobble- to boulder-size clasts supported within a grayish brown and clay-rich matrix. Clasts consist mainly of Cretaceous and Tertiary igneous rocks plucked from the highlands surrounding Baggs Creek and Cottonwood Creek, where scour channels are carved into the landscape (fig. 2, photo A). Outwash gravels occur at 10–20 m above the modern floodplain. Includes small (<1 km^2) and isolated rock-glacier moraines that occur at 2,080–2,130 m above mean sea level (Scarberry, 2016a).

Ts **Basin sediments (Tertiary)**—Stratified, cross-bedded or thickly bedded, lenticular, poorly to moderately lithified, light gray to light brown, alluvial deposits of the Deer Lodge Valley basin sequence (Derkey and others, 1993). Predominately poorly sorted, massive sandy or silty mudstone with blocky fracture and grayish orange to very pale-orange color. Includes very poorly to moderately sorted sand to boulder conglomerate beds as much as 10 m thick comprised of basalt, rhyolite, granite, and siltstone clasts (P. Yakovlev, written commun., 2017). Includes bentonite and ash beds that are continuous for up to several kilometers (Berg and Hargrave, 2004). The unit is tens of meters thick in the map area and approaches a total thickness of 3 km in the middle of the Deer Lodge Valley (Berg and Hargrave, 2004).

Bedrock

Middle Eocene Volcanics

Tr **Rhyolite (Tertiary)**—Light to medium gray or pink, flow-banded rhyolite that contains 5–10 percent plagioclase and quartz phenocrysts that are 1–2 mm long set in a fine-grained groundmass (Derkey and others, 1993). The unit correlates with spherulitic and lithophysal rhyolite flows, units Trf and Trp, described by Ruppel (1963) and Mosolf (2015), respectively. A radiometric age from the base of the 400 to 500-m-thick flow sequence near Avon (fig. 1) yielded an age of 40.8 Ma (U-Pb on zircon); (Mosolf, 2015).

Late Cretaceous Igneous Rocks

Boulder Batholith (cross-section only)

The Boulder Batholith is not exposed in the map region but is shown in the cross-section with the EMV sequence in the Emery mining district representing a roof pendant. The intrusive contact between the batholith and the EMV may be interpreted as essentially concordant in the region, and Ruppel (1961, 1963) believed that the batholith exhibits a laccolith-like geometry. Emplacement of the batholith into the EMV may have produced flexural pathways for mineralizing fluids, and it's likely that the roof of the batholith lies at shallow depth beneath the Emery mining district (Robertson, 1953).

Kg **Granite and aplite (Late Cretaceous)**—Massive, jointed granite outcrops that form the principal pluton, by volume, of the Boulder Batholith. Coarse, medium, and fine varieties occur and exhibit normal-zoned plagioclase (45–50%), orthoclase (20–30%), and quartz (5–10%) (Berg and Hargrave, 2004). Contains accessory amounts of sphene, apatite, magnetite, and rare zircon (Weeks, 1974). The Butte Granite has an age of 76.28 ± 0.12 Ma (SHRIMP-RG U-Pb on zircon) (Martin and Dilles, 2000). Aplite forms light tan, sheet-like outcrops that appear bedded in places but lack volcanic or sedimentary structures. The rock is typically fine-grained with sugary and equigranular texture, although moderately coarse varieties occur. Minerals include 10% biotite and near equal amounts of quartz and feldspar. Includes small masses of pegmatitic rocks that may contain radiating tourmaline crystals, potassium feldspar, and plagioclase. Aplite on the west side of the Boulder Batholith, north of Butte, is 74.8 ± 0.6 Ma (LA-ICP MS, U-Pb on zircon; M. Schmitz, Boise State University, written commun., 2016).

Kdi **Gabbro–Diorite intrusions (Late Cretaceous)**—Isolated and brecciated bodies that cross cut contacts locally in the northern part of the Sugarloaf Mountain 7.5' quadrangle (Derkey and others, 1993). Intrusions form a series of aligned rock towers mantled by lava flow breccia near Sugarloaf Mountain (Scarberry, 2016a). In part, they represent intrusive equivalents to the basalt–andesite lava sequence (Kema) and most, if not all, of the intrusions pre-date rocks of the Boulder Batholith (Kg). A diorite intrusion located approximately 8.5 km south of Cottonwood Creek (fig. 1 inset: KCS-13-12; 46.28729N, -112.59713W) has a U-Pb weighted mean age of 79.8 ± 2.0 Ma (LA-ICP MS on zircon, 95% confidence).

Elkhorn Mountains Volcanics (EMV)

The EMV cover 25,000 km^2 along the flanks, and top, of the Boulder Batholith north of Butte (fig. 1). The volcanic deposits formed a 4.6-km-thick volcanic plateau in the region during the height of volcanic activity (Smedes, 1966). Regional studies describe lower, middle, and upper EMV sequences (table 1). The lower EMV sequence is primarily basalt–andesite lavas, and dacite porphyry lavas and dome complexes. The middle EMV sequence consists of several large-volume rhyolite ignimbrites (Scarberry and others, 2016), and the upper sequence contains volcanogenic sediments and water-laid volcanic deposits.

Table 1. Summary of the volcanic stratigraphy of the Elkhorn Mountains Volcanics.

Sequence	Rock Types	Thickness (m)
Upper	Bedded and water-laid tuff and andesitic volcanogenic sedimentary rocks ranging from conglomerate to mudstone. Isolated lenticular beds of fresh-water limestone and minor andesite.	530–2,100
Middle	At least three large-volume regional rheomorphic rhyolite ignimbrites that contain debris from the lower member. Includes ash-fall crystal tuff and subordinate thin beds of water-laid tuff.	450–2,300
Lower	Basalt–andesite lavas and andesitic welded tuff. Also contains autobrecciated lavas, lapilli tuffs, and minor, thin, interlayered silicic ash-flow tuffs. Volcanic breccia and conglomerate increase up the section. Clast size also increases up the section. Includes dacite lavas, flow domes and volcanogenic sediments, such as lahar deposits.	200–1,500
Diorite	Dioritic rocks pre- and post-date middle member deposits. Diorite occurs as dikes, sills, laccoliths, and in association with dacite flow and dome complexes.	300–600

Data sources: Klepper and others, 1957, 1971; Ruppel, 1963; Becraft and others, 1963; Smedes, 1966; Weeks, 1974; Scarberry, 2016a,b; Scarberry and others, 2016; Olson and others, 2016.

This map treats all basalt–andesite lavas in the Emery mining district as part of the lower EMV sequence (table 1). Previous workers do not agree on the stratigraphic position of the basalt–andesite lava sequence. The lavas are approximately 400 m thick and often crop out at topographic elevations higher than the middle EMV ignimbrite and breccia sequence. Basalt–andesite lavas form a sharp contact with the middle EMV ignimbrite sequence less than 0.5 km southeast of the Emery mining district (see map). The high topographic expression of the basalt–andesite lavas may have led Ruppel (1961) and Derkey and others (1993) to conclude that they erupted prior to, during, and after rhyolite ignimbrite volcanism. It is difficult to place confidence in the interpretation that the lava sequence is interstratified with rhyolite ignimbrites in this region of dense forest and poor exposure, as proposed by these previous workers. Based on lateral changes in volcanic textures, Scarberry (2016a) argued that juxtaposition of the basalt–andesite lavas with middle EMV ignimbrite and breccia is a relic of Late Cretaceous caldera formation (see cross-section). The proposed caldera margin of Scarberry (2016a) is located 3 km southwest of the Emery mining district and, in part, coincides with a low magnetic anomaly (fig. 4). Extensively silicified and altered rocks show low magnetic anomalies in caldera settings of the San Juan Mountains in southwestern Colorado (Luedke and Burbank, 2000).

Middle Member

Kemr **Rhyolite ignimbrite (Late Cretaceous)**—Multiple pulses of explosive rhyolite volcanism are recorded by these deposits. The base of the sequence crops out near the head of the middle fork of Cottonwood Creek, where it consists of approximately 20 m of coarse-bedded volcanogenic, clast-supported sediment that grades upward from sand to conglomerate beds (Scarberry, 2016a). Volcanogenic sands show evidence of fluvial reworking of lower EMV lavas (fig. 3A) prior to emplacement of the ignimbrites. Scarberry (2016a) groups the ignimbrite deposits into two sequences. (1) The lower sequence is gray to green, welded, ash-flow tuff and tuff breccia that is recognized by conspicuous secondary textures and minerals, including silicified breccia, purple and green oxides, and patches of disseminated sulfide mineralization. A sample of the lower sequence collected approximately 7 km south of Cottonwood Creek (fig. 1 inset, KCS-13-44; 46.28289N, -112.52848W) has a U-Pb weighted mean age of 77.4 ± 1.7 Ma (LA-ICPMS on zircon, 95% confidence). Maroon vitrophyre that crops out southeast of Sugarloaf Mountain is at least 15 m thick and may separate deposits of the upper and lower sequences. (2) The upper ignimbrite, or ignimbrites, are a massive, medium to dark gray, cliff-forming sequence of ash-flow tuff. These deposits are recognized by abundant 0.5 to 2.0-mm-long plagioclase phenocrysts, polylithic rip-up clasts, and fiamme (fig. 2, photos B and C) and vitroclasts that are 1–5 cm long. Pebble-sized, rip-up clasts of porphyritic basalt–andesite lavas (Kema), granite (Kg), and metasedimentary rocks (Kms) occur. An exposure of the upper tuff sequence just south of Cottonwood Creek (see map plate, KCS-13-28) has a U-Pb weighted mean age of 78.5 ± 2.2 Ma (LA-ICP MS on zircon, 95% confidence). The total thickness of the rhyolite ignimbrite sequence decreases markedly in the map region, from 900 m (2,953 ft) near Sugarloaf Mountain (Scarberry, 2016a) to less than a few meters thick in the Emery mining district (Robertson, 1953).

Kemb **Volcanic breccia (Late Cretaceous)**—Blocks of angular to subangular tuff, welded tuff, and dioritic intrusive rocks packed tightly in a fine ash matrix. Excellent exposure of clast-supported breccia occurs at Cliff Mountain, where the sequence likely correlates with unit Kvp of Ruppel (1963). The polylithic breccia contains 10–30 m blocks of andesite, related intrusions, and metasedimentary rocks (units Kema, Kdi, and Ksm). Scarberry (2016a) interpreted the unit as caldera collapse breccia that is in part intercalated with the middle member ignimbrite sequence (Kemr). The breccia sequence is up to 400 m (1,312 ft) thick.

Lower Member

Kema **Basalt–andesite fissure breccia, flow breccia, and lava flows (Late Cretaceous)**—Lava flow breccia forms massive, blocky, subrounded boulder outcrops that are continuous for over 2 km. The breccia is a dull brown in outcrop and fresh surfaces are blue-gray with aphanitic texture. The rock contains 60–70% plagioclase microlites, minute pyroxenes, and some amphibole. Pyroxene and amphibole are strongly altered to chlorite. A northeast-trending ridge of fissure breccia (fig. 2, photo D) surrounds intrusions (Kdi) southwest of Sugarloaf Mountain (Scarberry, 2016a). The following description of the basalt–andesite lava sequence is derived from Robertson (1953) unless otherwise noted. Basalt–andesite lavas and breccia host ores in the Emery mining district. Basalt lavas may occur lower in the sequence and andesite lavas higher (Al-Khirbash, 1982). Collectively the lava flows are a dark greenish-gray rock containing white amygdules (fig. 2, photos E and F) and generally characterized by small white phenocrysts of feldspar (Pardee and Schrader, 1933). Discrete textural and mineralogical varieties occur and include feldspar–pyroxene basalt, pyroxene basalt, amygdaloidal basalt, and andesite. Feldspar–pyroxene basalt occurs relatively low in the sequence, overlies breccia, and contains approximately 25 percent 2 to 4-mm-long phenocrysts of labradorite (16%), clinoenstatite (6%), and augite (3%). Pyroxene basalt contains 1 to 2-mm-long labradorite, 0.5 mm long or smaller olivine (fig. 3B), 2 to 4-mm-long diopside, and 2-mm-long augite phenocrysts with accessory magnetite. Amygdaloidal zones are common at the contact between individual flows of both the feldspar–pyroxene basalt and pyroxene basalt sequences. The amount of amygdaloidal material varies from a small percentage to about half the rock. Amygdules consist of spherical to irregular shaped, sand to fist-size mixtures of chalcedonic quartz, carbonate, hematite, chlorite, and epidote. Red andesite lavas contain plagioclase laths, chloritized amphibole, and pyroxene phenocrysts. The conspicuous red color of the andesite lava is due to oxidation of iron minerals to hematite that appears to cement mineral grains in the groundmass. The estimated total thickness of the lava sequence, including breccia, ranges from approximately 400 m (Scarberry, 2016a) to 600 m (Robertson, 1953; Derkey and others, 1993). North of Cottonwood Creek the vent coincides with a magnetic anomaly (fig. 4; cross-section). Borehole logs from Al-Khirbash (1982) suggest that the basalt–andesite sequence is more than 1 km thick underlying the Emery mining district.

Ksm **Metamorphosed sedimentary rocks (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 (1993). The protolith was likely siliceous mudstone and sandstone of the middle siliceous unit of the Colorado Formation (Ruppel, 1963); equivalent to the Frontier and Mowry Formations described by Vuke (2011). The unit approaches ~120 m (~390 ft) in total thickness.

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GIS production: Paul Thale and Christopher P. Smith, MBMG. Map layout: Susan Smith, MBMG. Editing: Susan Barth, MBMG.

Montana Bureau of Mines and Geology

MBMG Bulletin 137, Plate 1

Geologic Map of the Emery Mining District, Powell County, Montana

Kaleb C. Scarberry and Stanley L. Korzeb

2018