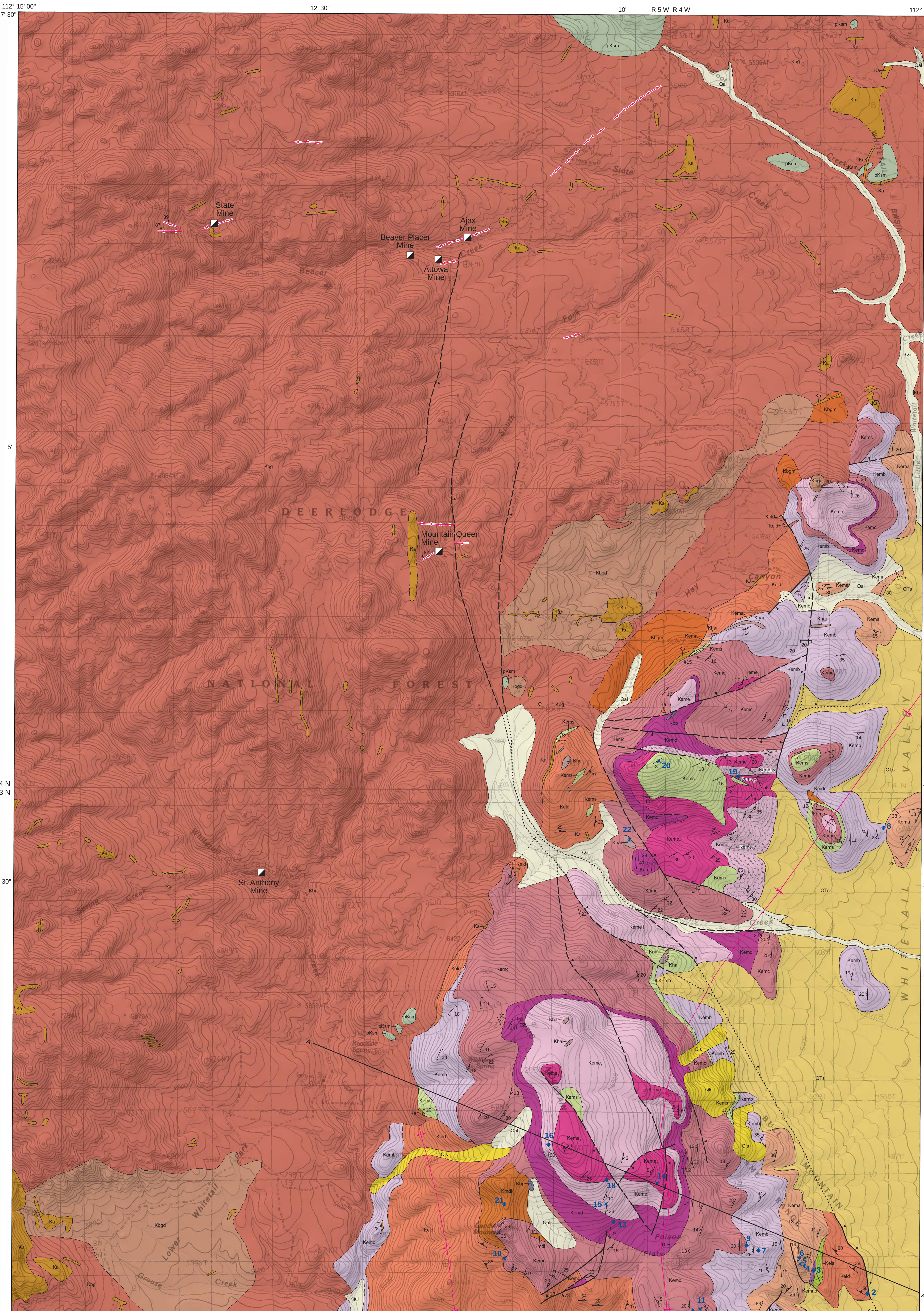
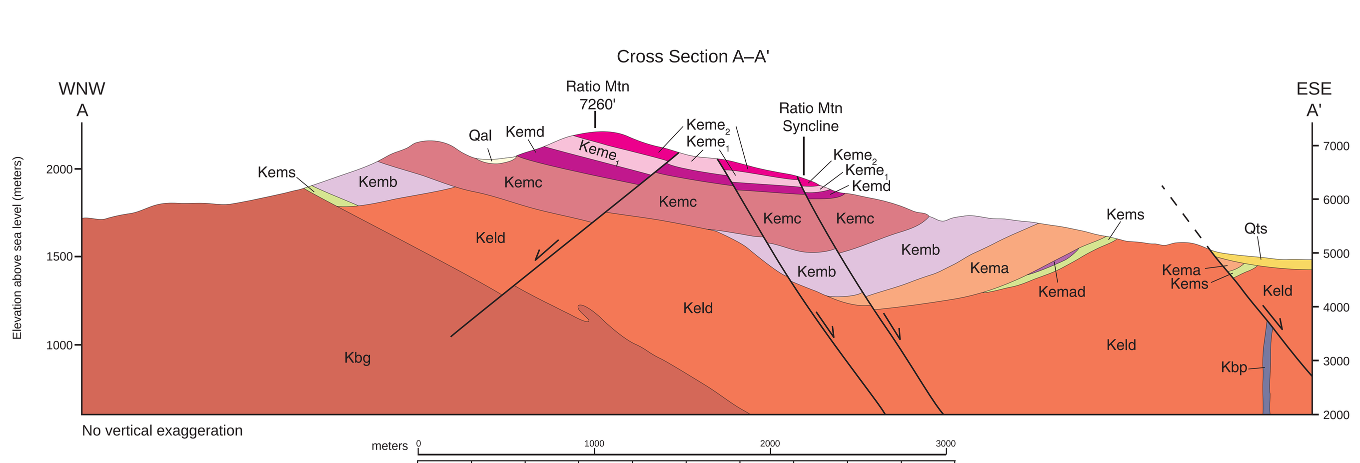


Base map produced by the United States Geological Survey
Ratio Mountain 1:24,000 scale quadrangle map
Control by: USGS, NOS/NOAA and USFS
Compiled from aerial photographs taken 1980
Field checked: 1981. Map edited: 1985
Projection: Lambert Conformal Conic
Grid:1000 meter Universal Transverse Mercator Zone 12
UTM grid declination: 0°15' West
1985 Magnetic NorthDeclination: 16°30' East
Vertical Datum: National Geodetic Vertical Datum of 1929
Horizontal Datum: 1927 North American Datum

SCALE 1:24,000
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



EDMAP 10

Geologic Map of the Ratio Mountain 7.5' Quadrangle, Southwest Montana

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2016

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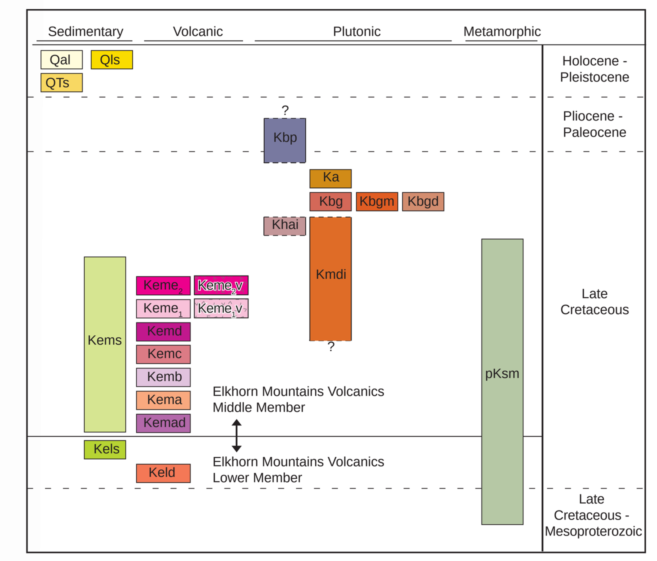
GIS production: Yiwen Li and Paul Thale, MBMG. Map layout: Susan Smith, MBMG.

CORRELATION CHART



MAP SYMBOLS

- Contact, showing dip direction: solid (± 15 m); dashed (±15-100 m); queried (>±100 m)
- Gradational contacts within the Butte pluton
- Fault, showing dip direction: solid (± 15 m); dashed (±15-100 m); queried (>±100 m)
- Attitude of rheomorphic lineation (bidirectional)
- Vein, showing dip direction
- Strike and dip of flow banding
- Strike and dip of rheomorphic foliation
- Bidirectional rheomorphic flow indicator
- Strike and dip of compaction foliation
- Strike and dip of bedding
- Sample location
- Historic mine

INTRODUCTION

The Ratio Mountain 7.5' quadrangle lies on the east flank of the Boulder Batholith (fig. 1) and contains exposures of late Cretaceous Elkhorn Mountain Volcanics, intrusions of the late Cretaceous Boulder Batholith, and Quaternary alluvial deposits. The area has moderate relief and ranges from grasslands along Whitetail Creek at 4800 feet (1465 m) on the east to forested mountains of high relief and up to 8425 ft (2570 m) on the west.

PREVIOUS MAPPING

Initial studies by the USGS-MBMG resulted in the publication of the preliminary geologic map of the quadrangle at a scale of 1:24,000 by Pinckney and Becraft (1961). These authors outlined the lithologies of the Butte pluton of the Boulder Batholith, and attempted to define the stratigraphy and structure of the Elkhorn Mountain Volcanics. Prostka (1966) completed a 1:24,000 geology map of the Dry Mountain 7.5' quadrangle, which adjoins the Ratio Mountain 7.5' quadrangle on the south (fig. 1). Prostka (1966) provided the first detailed description of the stratigraphy of the Middle Member of the Elkhorn Mountains Volcanics on the south flank of Ratio Mountain. The present study involved four man-months of field work, and focused on the stratigraphy and structure of the Elkhorn Mountain Volcanics and its contact with the Butte granite supplemented with petrographic, geochemical and geochronology studies.

GEOLOGIC SUMMARY

The Elkhorn Mountains Volcanics

The Butte pluton contacts the Elkhorn Mountains Volcanics (EMV) along on its eastern margin (fig. 1). A section of more than 950 m (3000 ft) of Lower and Middle Members of the EMV is exposed on the eastern side of Ratio Mountain where $^{40}Ar/^{39}Ar$ ages range from 84.7 Ma to 83.7 Ma from base to top (fig. 2).

The base of the section consists of the upper part of the Lower Member of the EMV. Here, lavas and domes of pyroxene-hornblende dacite are greater than 200 m (650 ft) thick. Prostka (1966) described this unit in the Dry Mountain 7.5' quadrangle, where it exceeds 500 m in thickness, as "dikes, sills, and a thick sheet of diorite porphyry," but it is evident that the unit is volcanic (fig. 3A). The dacite ranges from massive to strongly flow-banded with contorted, irregular bands that are commonly steeply dipping and form ramp structures. Individual dacite units are autobrecciated along their basal and upper contacts where monolithologic and angular dacite clasts are enclosed in a dacite matrix. Elsewhere, thin units of volcaniclastic sandstone are intercalated with the unit. The dacites appear to form a dome complex with up to 400 m of relief on the south flank of Ratio Mountain and in this area ignimbrite units A and B of the Middle Member pinch and terminate against the dacite topographic high.

The Middle Member of the EMV overlies the Lower Member and has an exposed thickness of 750 m of rhyolite with sparse amounts of dacite and andesite pyroclastic rocks (fig. 4A). The lowest three units consist of three regional rhyolite ignimbrites that have an aggregate thickness of up to 400 m and are termed units A, B, and C (Prostka, 1966). A small highly-altered andesite welded tuff (KemAd) occurs east of Ratio Mountain at the base of the Middle Member below unit A. Collectively, these rhyolites are weakly to strongly welded, contain abundant fiammé and have sparse phenocrysts (5 to 20 vol. percent) of plagioclase, biotite and trace amounts of opaques, local quartz, and possible pyroxene or hornblende. All the mafic minerals have been altered to mixtures of chlorite, muscovite, local epidote, hematite, and titanium oxides. Unit A is rheomorphically deformed throughout its exposed thickness; unit B exhibits moderate to strong rheomorphic deformation features in the middle half to two-thirds of the unit; unit C displays rheomorphic deformation features in its central one-third (fig. 3B, C, D, & E). Geochemical analyses (table 1) suggest these rhyolites are alkali-rich and weakly reversely zoned from slightly lower silica contents at their base to slightly higher silica content at their top (Fig. 4). The phenocryst contents of the tuffs generally also decrease slightly up section. Units A, B, and C are regionally extensive units that occur to the east in the Wilson Park 7.5' quadrangle (Scarberry, 2016) and to the northeast in the Boulder East 7.5' quadrangle (K. Scarberry and I. Kallio, written commun., 2016) in an area ~20 km by 35 km in extent and perhaps correlative with exposures of Middle Member in the Elkhorn Mountains and northern part of the Boulder Batholith (Klepper et al., 1956; Smedes, 1966; Smedes et al., 1988; Rutland et al., 1989). Each of these pyroclastic eruptions is therefore voluminous (>100 km^3; Scarberry et al., 2016).

Overlying unit C is a series of andesite to dacite unwelded airfall tuffs and associated volcaniclastic sandstones (unit D of Prostka (1966) and unit Kems), dacite to rhyolite ignimbrites (Unit E of Prostka, 1966), and dacite to rhyolite pyroclastic vent facies equivalent to unit E (fig. 4a). Together these units comprise the here-named Ratio Mountain caldera as well as extracaldera deposits. Exposures on Ratio Mountain include 90 m of Unit D and 110 m of unit E. Unit E is subdivided into a lower cooling unit of crystal-rich hornblende-pyroxene dacite ignimbrite ~60 m thick and an upper cooling unit of moderately crystal-rich hornblende-pyroxene-biotite ignimbrite zoned from a basal zone of dacite to an upper section of rhyolite (Fig. 3F). A pyroclastic vent approximately 1000 m by 1500 m in dimension is exposed in sections 6 and 31 on the north side of Pony Creek, about 3 km north-northeast of Ratio Mountain. Here, steeply dipping eutaxitic compaction foliation is observed in both an older crystal-rich tuff and a younger and cross-cutting moderately crystal-rich tuff (Fig. 3G). These pyroclastic vent facies rocks cut and overlie unit D and older EMV units, and are overlain to the west by 10 to 60 m of dacite airfall tuff and tuffaceous sandstone. The caldera is therefore characterized by steeply dipping pyroclastic feeders and intra- and possible extra-caldera airfall tuffs, tuffaceous sandstones, and two thin ignimbrites.

The EMV at Ratio Mountain are generally high in alkalis (K and Na), metaluminous, and calc-alkaline in composition (Rutland et al., 1989). Mafic to intermediate composition rocks are relatively enriched in large ion-lithophile elements (K, Rb, Sr, Cs, Ba, Rb) and Pb (fig 4B), which likely reflects assimilation of crustal rocks enriched in these elements. Silicic compositions are variably depleted in Sr, P, Ti, Nb, Ta and middle Rare Earth Elements (Sm, Eu, Dy) (fig. 4B), which likely reflects modest crystal-fractionation of plagioclase, apatite, amphibole and spinel compared to the Boulder Batholith, which shows little evidence for crystal fractionation (du Bray et al., 2012).

Butte Pluton and Other Intrusions

Two series of late Cretaceous intrusions are found in the Ratio Mountain quadrangle. Older more mafic bodies intrude the EMVs and include a small plug of quartz monzodiorite south of Ratio Mountain, several small dikes of pyroxene-hornblende ± biotite diorite and gabbro, and a pyroxene-olivine-biotite-phyric gabbro dike in the southeastern-most part of the quadrangle. The $^{40}Ar/^{39}Ar$ ages from diorite at Ratio Mountain and in the Wilson Park 7.5' quadrangle are 81 to 79 Ma (Fig. 2).

The main body of the Butte pluton consists of medium- to coarse-grained biotite-hornblende granite. Near the contact with the EMVs Pinckney and Becraft (1961) mapped several bodies of light-colored Butte granite, darker-colored medium-grained granite to granodiorite, and fine-grained biotite-rich granite to granodiorite. Contacts of these units are gradational, and generally parallel the contact with the EMV. Several roof pendants of fine- to medium-grained massive to bedded quartz-feldspar-biotite-muscovite rock are found in the northeast part of the quadrangle where they are intruded by numerous aplite bodies (fig. 3H). Steeply dipping dikes and gently dipping sill-like bodies of alaskite and aplite containing sparse biotite are found throughout the Butte pluton, where they are the youngest intrusions. A few aplite dikes are found along the contact with the EMVs and intruding the EMV within 300 m of the contact.

U/Pb zircon ages for the Butte granite are 74.5 ± 0.9 Ma (Lund et al., 2002) and 76.28 ± 0.14 Ma (Martin et al., 2002). Hornblende compositions yield barometric estimates of 2.1 to 2.4 (± 0.2) kb pressure for Butte granite at Ratio Mountain based on the calibration of Anderson and Smith (1995), suggesting emplacement depths of 7 to 8 km (J. H. Dilles, written commun., 2015). The Butte granite produced moderate metamorphic effects in the adjacent EMV. Hornfels with conspicuous biotite is present within 500 m of the contact, and locally biotite extends up to 1,500 m. EMV in distal positions is characterized by greenschist assemblages with chlorite and albite and common epidote, hematite, and titanium oxides.

HYDROTHERMAL MINERAL DEPOSITS

A series of polymetallic fissure veins generally <1 m in width have been mined and prospected for lead, zinc, silver, copper, and gold in the Ratio Mountain quadrangle, including the Mountain Queen, Ajax, Attowa, State and St. Anthony Mines in the Butte pluton. A few small veins extend into the older EMV east of the Butte pluton. Field reconnaissance investigations indicate these veins consist principally of quartz and sulfides that include pyrite, galena, sphalerite, chalcopyrite, and local arsenopyrite. Tourmaline is present in the quartz-rich veins at the State Mine. The veins strike east-west to northeasterly (azimuths = 50°–105°) and dip steeply to the north (80–90°). Fine- to medium-grained sericite (muscovite) is present in alteration selvages ranging from a few mm to 25 cm thickness. Two muscovite samples, one from the State Mine, and one from the Ajax Mine, yield $^{40}Ar/^{39}Ar$ plateau ages of 75.12 ± 0.25 (95 percent confidance) Ma and 73.81 ± 0.12 (95 percent confidance) Ma that are only slightly younger than the Butte granite (fig. 2).

STRUCTURAL GEOLOGY

The eastern contact of the Butte Granite with the EMV strikes N 30-35°E both regionally and in the Ratio Mountain quadrangle. To the south and east of Homestake Pass, the contact is steeply east-dipping (Rutland et al., 1989). Exposures of the contact in the Ratio Mountain area are sparse, but all observations indicate the contact dips moderately to shallowly (40–20°) southeast. There is no apparent shear or deformation along the contact.

The EMV east of the Butte pluton have open and gentle folds with axes that trend N30°E to approximately north-south and plunge gently both to north and south. The EMV units have dips that are generally <30°. A series of east-west striking and north-south striking normal faults with small displacement (<100 m) occur near the Ratio Mountain caldera, and may be associated with caldera collapse. Similar normal faults and steeply dipping eutaxitic compaction foliation are also documented for the pyroclastic vent complex at Big Butte, at Butte, Montana (Dresser, 2000; Houston and Dilles, 2013a, b).

The rheomorphic parts of EMV ignimbrites A and B display prominent foliations with strong shearing lineations and local folds that result from post-emplacement flow (fig. 3B, C, & D). Although only a few measurements were made, these lineations are consistently oriented ~N30°E. Sense of shear is not known (top to SSW or NNE), but these rheomorphic deformation suggests deposition of the ignimbrites on surfaces of strong topographic relief as also indicated by the pinch-outs of units A and B against the topographic high made by the Lower Member dacites.

A series of Quaternary normal faults help define the western margin of Whitetail Valley. In the southeastern-most part of the Ratio Mountain Quadrangle, a down-to-the-east normal fault (N25°W) has a small and degraded scarp (<2 m) about 1 km in length between EMV and Quaternary pediment gravels on the east. This fault is inferred to extend north-northwest into bedrock and defines the steep eastern escarpment of Ratio Mountain where it has 200–300 m of normal offset of EMV stratigraphy. This fault system extends northerly into the Butte pluton where it bends to a north-south strike. A notable topographic break across the fault projection suggests displacement of ~300 m down-to-the-east as far north as the Ajax Mine.

SEDIMENTS

Qal Quaternary-Holocene alluvial deposits along modern stream drainages.

Qls Landslide deposits of unsorted mixture of silt, clay, sand, gravel and boulders.

QTs Dissected gravels on pediment surfaces along the west side of Whitetail Creek valley.

IGNEOUS AND VOLCANICLASTIC ROCKS
BOULDER BATHOLITH (LATE CRETACEOUS)

Butte Pluton of Boulder Batholith

Ka Alaskite bodies and aplite-pegmatite dikes that contain sparse (<5 vol. percent) biotite. Unit is medium- to fine-grained and contains subequal proportions of quartz, K-feldspar, and plagioclase. Alaskite bodies cut other units of the Butte pluton.

Kbg Granite of Butte pluton, includes map units "cm" (undivided) and "cl "(light-colored) of Pinckney and Brecraft (1961): medium- to coarse-grained granite consisting of plagioclase, K-feldspar up cm long, and quartz, with 15 to 20 vol. percent mafics that include biotite, hornblende, and accessory magnetite, titanite, apatite, ilmenite, and zircon.

Kbgm Granodiorite of Butte pluton, map unit "ml" of Pinckney and Brecraft (1961): Contacts with Kbg and Kbgd are gradational. Consists of medium-grained (average 1.5–2 mm) equigranular granite and granodiorite.

Kbgd Granodiorite of Butte pluton, map unit "mld" of Pinckney and Brecraft (1961): Contacts with Kbg and Kbgm are gradational. Consists of medium-grained granite and granodiorite with abundant small clusters of euhedral biotite.

Mafic to Intermediate Composition Dikes and Plugs of the Boulder Batholith

Kbp Alkali basalt dike with conspicuous phenocrysts of augite (5–10 mm), olivine, and biotite set in a fine-grained groundmass of augite and plagioclase, and minor Fe-Ti oxides. Equivalent of the unit "K" of Prostka (1966). Dike cuts the lower member of the Elkhorn Mountain Volcanics in the southeast part of the quadrangle

Khai Fine- to medium-grained porphyritic to seriate-textured diorite to gabbro dikes, sills and plugs. Unit contains 15 to 20 vol. percent phenocrysts of pyroxene, hornblende, biotite , and plagioclase in a fine-grained groundmass of plagioclase and pyroxene. This unit is similar to diorite sills and dikes described by Scarberry (2016) for the adjacent Wilson Park Quadrangle. Hornblende from dike sample CWO-14-10 yielded a $^{40}Ar/^{39}Ar$ weighted mean plateau age of 80.02 ± 0.40 Ma (95 percent confidence) where it intrudes unit C ignimbrite of the Middle Member of the Elkhorn Mountain Volcanics (D. Miggins, written commun., 2015).

Kmdi A 500 m-diameter monzodiorite stock intrude EMV units Keld and Kemc on the southwest flank of Ratio Mountain. The intrusion is medium-grained and has a seriate texture, and consists of plagioclase, K-feldspar, quartz and 15 to 20 vol. percent chlorite replacements of primary hornblende and/or pyroxene.

MIDDLE MEMBER OF THE ELKHORN MOUNTAIN VOLCANICS

Kems Volcaniclastic sandstones, airfall tuffs, and siltstones that typically display poorly developed ~1 cm planar bedding with local graded and reversely graded beds; minor amounts of cross-bedding is observed with wavelengths of 10–50 cm. Composition of volcanic material is commonly andesite. Sandstone is clast-supported, and contains clasts of volcanic lithics, plagioclase, and altered pyroxene and hornblende. Mafic minerals and plagioclase are altered principally of chlorite, epidote, albite and local specular hematite. Exposures of Kems unit up to 20 m thick overlie Keld and are overlain by unit Kemad and Kema; Kems unit up to 60 m thick overlie unit Kemb and are overlain by unit Kemc; and Kems unit is 10 to 60 m thick where it overlyies unit e$_2$ and the ignimbrite vent range.

Keme$_2$ Upper ignimbrite of unit e, typically up to 50 m thick, poorly welded with 10 to 15 vol. percent crystals. This unit is typically a cliff-forming, and locally, has a basal black vitrophyre 1–3 m thick, and an upper section that is white and vapor phase altered. The basal vitrophyre is andesite to dacite and contains 15 vol. percent plagioclase, pyroxene and hornblende altered to chlorite and epidote, and sparse opaques. The middle and upper parts of the tuff are white, devitrified, locally columnar jointed rhyolite, and contains 15–18 vol. percent plagioclase, pyroxene altered to chlorite and traces of opaques and quartz. A $^{40}Ar/^{39}Ar$ age of 83.7 ± 0.3 Ma was obtained from hornblende from NHO-15-47 (T. Horton, D. Miggins, & J. Dilles, written commun., 2016).

Keme$_2$v Vent facies of the unit e$_2$ rhyolite ignimbrite, characterized by fiamme and compaction foliation with subvertical orientation. Cuts vent facies of e$_1$ ignimbrite and e$_1$ ignimbrite, and is locally overlain by unit e$_2$ and volcanic sandstones. The vent complex is buried by unit e$_2$ on the west, but has maximum dimensions of ~200 by 500 m.

Keme$_1$ Lower ignimbrite of unit e, typically up to 60 m thick, poorly to moderately welded andesite to dacite with ~30 percent crystals of plagioclase, clinopyroxene, hornblende, biotite, and opaques. Mafic silicates largely altered to chlorite and epidote, Unit is typically dark gray green and forms ledges.

Keme$_1$v Vent facies of the unit e$_1$ rhyolite ignimbrite, characterized by fiamme and compaction foliation with subvertical orientation. Unit is locally overlain by units e$_1$ and e$_2$ and also volcanic sandstones.

Kemd This is a distinctive unit of andesitic airfall tuff and reworked volcaniclastic sandstone, siltstone and conglomerate up to 90 m thick that overlies unit C and underlies unit E (otherwise is broadly similar to other exposures of Kems in the section). Contains lithic fragments, plagioclase, pyroxene and/or hornblende and sparse biotite altered to chlorite and epidote, and opaques.

Kemc Rhyolite ignimbrite unit c. Unit is up to 100 m thick, and is typically moderately welded at its base, locally rheomorphic in the lower 20 to 40 percent of the tuff, and is weakly welded in its upper part. Unit is typically light-colored, buff to tan, crystal poor tuff with 10 to 15 vol.% plagioclase, biotite (1 to 3 vol. percent, 1 mm), sparse opaques, and rare quartz. Crystal content generally decreases upsection, and the upper half of the tuff contains large partially flattened and hydrothermally altered pumice up to 30 cm long, and 1 to 5 vol. percent volcanic lithic fragments up to 10 cm diameter.

Kemb Rhyolite ignimbrite unit b. Unit is up to 200 m thick and is conspicuously zoned. The base is moderately welded and contains 15 percent crystals; this section is overlain by a strongly rheomorphic ignimbrite with abundant small pumice (10 x 1 cm) that contains 15–20 vol. percent crystals; the welding and rheomorphic deformation decreases upward in the upper part of the tuff. Crystal content also decreases to 10 to 15 percent in the uppermost exposures. This is the most crystal rich of units a, b, and c, and it contains small plagioclase, abundant (3 to 5 vol. percent) and comparatively large (1–2 mm) biotite phenocrysts altered to chlorite and hematite, and sparse opaques. An U/Pb age of 81.7 ± 0.8 Ma (95 percent confidence) for was obtained for zircon from sample NHO-15-63 via Shrimp-RG (N. Olson and J. Dilles, written commun., 2016).

Kema Rhyolite ignimbrite unit A. This unit is up to 160 m thick and displays strong rheomorphic deformation throughout the section except the basal 5–10 m. Rheomorphic textures includes strong lineations (typically oriented north-northeast to south-southwest) and folded fiamme that have aspect ratios of ~100:10:1. The unit is moderately welded and rheomorphic to its uppermost exposures, suggesting the top has been eroded and is now missing. The unit is typically crystal-poor (7 to 10 vol. percent), and contains 5 to 7 percent plagioclase with sparse biotite (1–3 mm, 1 percent, altered to chlorite) and traces of quartz and possible chlorite-altered pyroxene. The crystal content decreases slightly up section. Laser ablation-ICP analysis of zircons from a sample of unit A yield a weighted mean U/Pb age of 84.9 ± 2.6 (95 percent confidence; C. Older and N. Olson, written commun., 2014).

KemAd Dark gray-green moderately welded andesite ignimbrite up to 25 m thick with 25–30 percent crystals. It is characterized by plagioclase (10 to 15 percent), clinopyroxene (10 percent), and a few percent opaques and biotite crystals and abundant, small (<5 cm long) black fiamme. Mafic silicates are altered to chlorite. The unit is locally exposed at the base of the section southeast of Ratio Mountain, where it overlies 5–25 m of unit Kems.

LOWER MEMBER OF THE ELKHORN MOUNTAIN VOLCANICS

Kels Dark gray-green poorly bedded volcaniclastic sandstone, conglomerate, siltstone and air-fall tuff units similar to unit Kems are found intercalated with unit Keld, and are localized near autobrecciated flow tops and bottom of dacite lavas. Compositions are typically andesite to dacite.

Keld Dacite lavas, domes, and auto-brecciated lavas and domes, likely in excess of 300 m thickness. This unit is conspicuously flow-banded in most exposures, with ramp-like flow-banding ranging from gentle to steep dips that are exhibited in flows or domes units up to 50 m thick. Auto-brecciated dacite is found locally near the base or top of individual lava flow units and is characterized by 1–10 m of dacite lava containing subangular decimetric clasts of dacite. This unit was mapped as a diorite porphyry by Prostka (1966) in the adjacent Dry Mountain Quadrangle, but the presence of both auto-breccias and intercalated volcaniclastic sedimentary units as well as the local topographically high domes demonstrate an extrusive origin. No similar lithologies are found in the middle member of the EMV. The lavas contain 30 to 35 vol. percent crystals of plagioclase, augite, hornblende, trace biotite, and Fe-Ti oxides. Mafic silicates are partly altered to chlorite and epidote.

METAMORPHIC ROCKS

pKsm Metamorphic rocks, undivided, that occur as large roof pendants, xenoliths, and xenolith swarms within the Butte pluton. Pinckney and Becraft (1961) identified these metamorphic rocks as being dominantly composed of Elkhorn Mountain Volcanics. The largest exposures in the northern part of the quadrangle consist of fine-grained granoblastic quartz, K-feldspar, and sodic plagioclase accompanied by 5 to 15 vol. percent biotite and muscovite. Rock ranges from massive to conspicuously layered on the mm to cm scale, the latter suggesting meta-sedimentary protoliths.

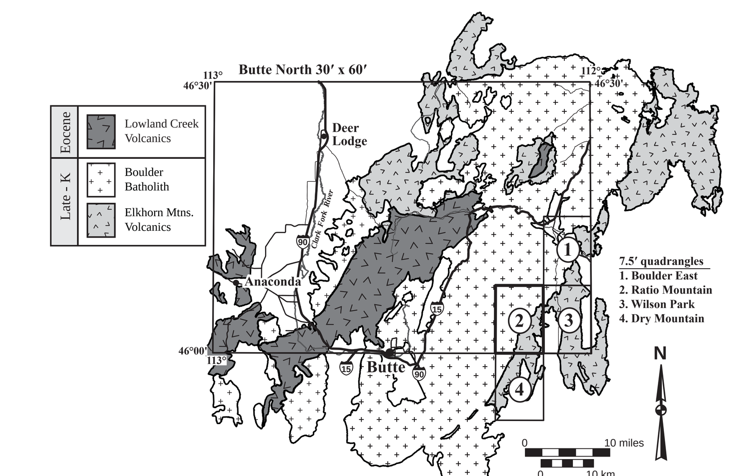


Figure 1. Location map

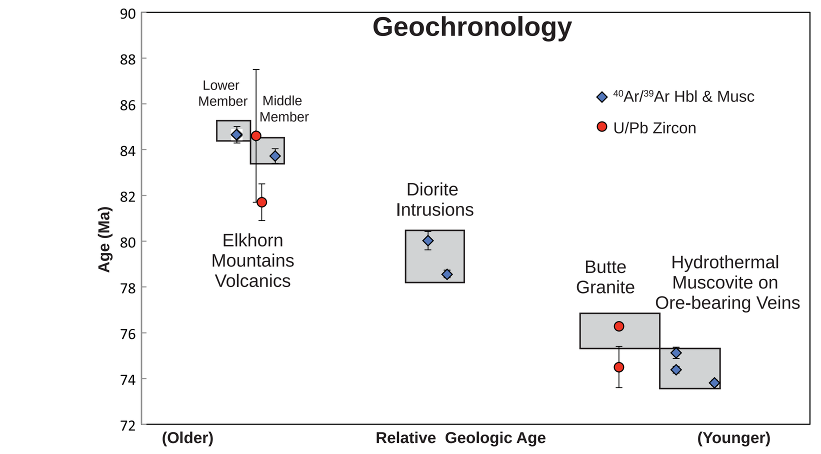


Figure 2. Summary of geochronology of the Ratio Mountain quadrangle ($^{40}Ar/^{39}Ar$ weighted mean step-heating release plateau ages from OSU laboratories by D. Miggins, T. Horton, J. Dilles, I. Kallio, and N. Olson; U/Pb weighted mean ^{207}Pb-corrected $^{206}Pb/^{238}U$ zircon ages from N. Olson, C. Older, and J.H. Dilles). Note 79 Ma age of diorite intrusion is from Wilson Park quadrangle. Ages of Butte granite are from Lund et al. (2002) and Martin et al. (1999). All errors are 2 sigma (95 percent confidence).

Table 1: Major and trace element compositions of igneous rocks from the Ratio Mountain quadrangle.

	Lower Member		Middle Member																		Cross-Cutting Intrusions		
Lithology	Keld	Keld	Kemad	Kema	Kema	Kema	Kemb	Kemb	Kemb	Kemc	Kemc	Kemc	Kemd	Keme$_1$	Keme$_1$	Keme$_1$	Keme$_{1v}$	Keme$_2$	Keme$_{2v}$	Kems	Kmdi	Khai	Kbp
Sample ID	NHO15-31	NHO15-23	NHO15-24	NHO15-25	NHO15-26	NHO15-27	NHO15-29	NHO15-63	NHO15-30	NHO15-48	NHO15-33	NHO15-35	NHO15-39	NHO15-47	NHO15-41	NHO15-46	NHO15-60	NHO15-42	NHO15-61	NHO15-55	NHO15-49	CWO14-09	NHO15-38
Lat (WGS84)	45.997307	46.002288	46.004547	46.005078	46.004930	46.005471	46.006403	46.046953	46.006885	46.005526	46.000768	46.000635	46.009073	46.012839	46.010789	46.016450	46.052077	46.012854	46.052077	46.053281	46.010720	46.045798	45.995529
Long (WGS84)	-112.141949	-112.133258	-112.140246	-112.141680	-112.142366	-112.142326	-112.147777	-112.130886	-112.150228	-112.182727	-112.155661	-112.157455	-112.167616	-112.162374	-112.168915	-112.176532	-112.151214	-112.168879	-112.151214	-112.162236	-112.182889	-112.166151	-112.139100
Reference #	01*	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23*
SiO_2	60.71	62.54	56.52	68.11	71.23	70.07	66.77	69.10	71.00	68.96	69.29	72.26	56.90	61.43	61.90	63.46	65.18	72.57	74.24	59.81	62.45	55.14	52.06
TiO	0.602	0.485	0.691	0.509	0.486	0.515	0.517	0.483	0.380	0.567	0.468	0.379	1.001	0.707	0.657	0.558	0.582	0.286	0.316	0.685	0.522	0.762	0.706
Al_2O_3	15.10	15.47	15.65	14.94	14.05	15.13	15.47	15.59	14.05	15.21	15.05	13.94	15.69	17.28	18.07	18.23	17.10	13.53	13.29	16.13	16.04	15.84	11.69
FeO*	5.67	4.53	7.61	2.60	2.05	2.16	2.35	2.17	1.71	2.53	2.04	1.62	7.62	4.46	3.62	2.94	3.28	1.29	1.59	6.59	4.95	7.60	8.44
MnO	0.126	0.105	0.168	0.068	0.019	0.062	0.043	0.064	0.098	0.061	0.058	0.102	0.181	0.088	0.072	0.066	0.091	0.054	0.026	0.141	0.097	0.152	0.158
MgO	3.20	1.78	4.49	0.32	0.30	0.23	0.32	0.90	0.21	0.35	0.51	0.32	3.51	1.76	1.35	0.98	1.08	0.30	0.37	3.33	1.80	4.99	12.04
CaO	4.78	3.21	6.29	1.64	0.70	0.28	2.26	0.87	1.11	1.05	1.20	0.50	5.58	5.25	4.76	4.45	3.91	1.22	1.07	5.16	4.73	7.73	7.80
Na_2O	3.86	3.15	3.00	3.62	2.82	2.90	3.70	4.86	3.42	4.17	3.81	3.29	3.23	3.01	3.60	3.19	3.10	3.02	2.45	2.72	3.33	3.02	2.37
K_2O	2.70	3.71	0.54	5.04	5.19	5.87	4.57	5.05	5.14	5.32	4.21	5.23	1.85	3.30	3.33	3.56	3.59	5.11	5.30	2.68	2.82	2.78	3.20
P_2O_5	0.225	0.185	0.243	0.097	0.091	0.102	0.119	0.098	0.073	0.124	0.101	0.070	0.389	0.197	0.165	0.121	0.136	0.029	0.028	0.230	0.189	0.507	0.573
LOI (wt.%)	2.42	4.13	3.94	2.31	2.02	1.68	3.15	0.77	1.89	0.82	2.49	1.50	3.20	1.99	1.43	1.86	1.02	1.96	0.77	1.95	2.32	0.59	0.27
Ni	16	9	35	3	5	2	2	6	2	3	3	2	6	6	4	3	5	2	4	18	9	39	324
Cr	80	34	142	2	5	3	2	2	3	2	3	1	19	12	6	3	6	2	3	34	30	106	714
Sc	16	11	20	6	7	7	6	7	6	10	7	6	20	14	11	8	10	6	5	21	12	22	25
V	120	77	154	27	35	31	27	25	18	25	26	19	143	94	69	47	50	15	29	153	90	197	192
Ba	1288	1217	658	1307	1314	1368	1273	1498	1441	1621	1799	2227	706	1149	1230	1247	1344	1259	1389	879	959	851	784
Rb	49	76	13	157	173	199	126	98	134	132	118	140	46	81	73	104	90	137	143	71	64	74	73
Sr	688	560	1189	275	118	175	382	489	252	439	371	295	753	725	858	719	584	144	260	614	644	965	764
Zr	176	163	127	311	300	313	248	264	271	314	265	264	85	249	282	293	237	222	226	164	170	136	88
Y	22	20	25	27	24	27	27	28	27	35	30	30	20	24	23	23	25	28	27	22	22	20	15
Nb	10.2	10.3	8.4	17.7	16.4	17.9	14.0	15.1	15.0	17.2	14.9	14.5	6.7	11.3	10.9	11.5	12.2	15.8	15.6	10.1	11.9	10.1	5.9
Ga	16	15	18	16	15	16	17	16	13	16	17	14	19	18	19	19	18	12	12	18	18	19	13
Cu	22	23	49	9	5	8	0	16	3	3	3	3	2	12	6	2	9	1	3	66	0	58	44
Zn	75	66	92	52	38	48	55	50	50	51	55	41	88	64	55	51	62	24	22	80	59	87	78
Pb	12	16	13	23	26	18	19	22	21	24	24	24	13	17	18	17	21	15	24	22	14	11	8
La	34	29	29	48	44	46	45	48	47	61	47	43	23	37	37	38	36	44	44	30	32	31	17
Ce	60	55	54	88	87	90	84	87	85	110	87	87	49	69	67	73	71	86	84	60	59	61	33
Th	8	8	5	19	17	20	13	15	14	15	13	13	4	11	10	11	11	16	16	11	8	4	2
Nd	26	22	26	36	32	34	34	35	35	46	36	36	25	28	30	29	26	35	32	27	25	28	18
U	4	1	1	4	5	3	3	4	4	3	3	2	3	2	3	3	3	3	4	3	3	3	1

Analyses by XRF at the Geoanalytical Laboratory at Washington State University, 2016, normalized to 100% wt.% anhydrous. * Sample located 0.25 – 0.5 kilometers south of quadrangle boundary.

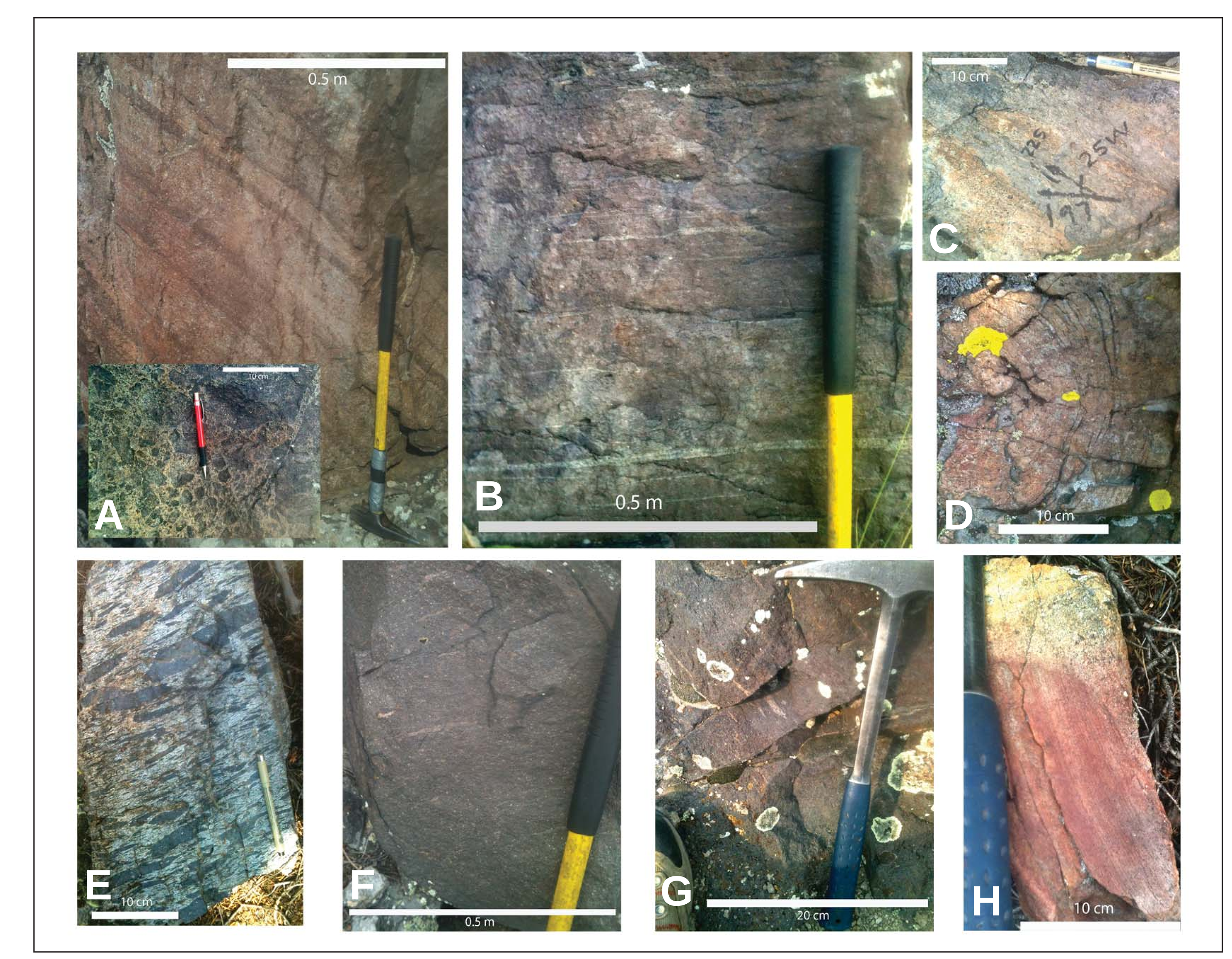


Figure 3. Photographs of Elkhorn Mountain Volcanics and older roof pendants. A. Lower member: flow-banded dacite lava (inset is autobrecciated lava); B. Middle Member, crystal-poor rhyolite ignimbrite A with strong planar-linear rheomorphic deformation; C. Middle Member, rhyolite ignimbrite B showing rheomorphic foliation surface with strong SSW-NNE oriented shear lineament; D. Middle Member, rheomorphic fold in rhyolite ignimbrite remnant below unit C; E. Fiammé in moderately welded rhyolite ignimbrite at base of unit C; F. Chocolate-brown, vitrophyre of moderately crystal-rich dacite to rhyolite ignimbrite unit E2 (outflow sheet); G. Steeply dipping compaction foliation and small fiamme of unit E2 in vent complex of the Ratio Mountain caldera; H. Metamorphosed planar-bedded arkosic sandstone containing muscovite and biotite (red) cut but aplite (yellow, upper part) in roof pendant in Butte granite in the northernmost part of the Ratio Mountain Quadrangle.

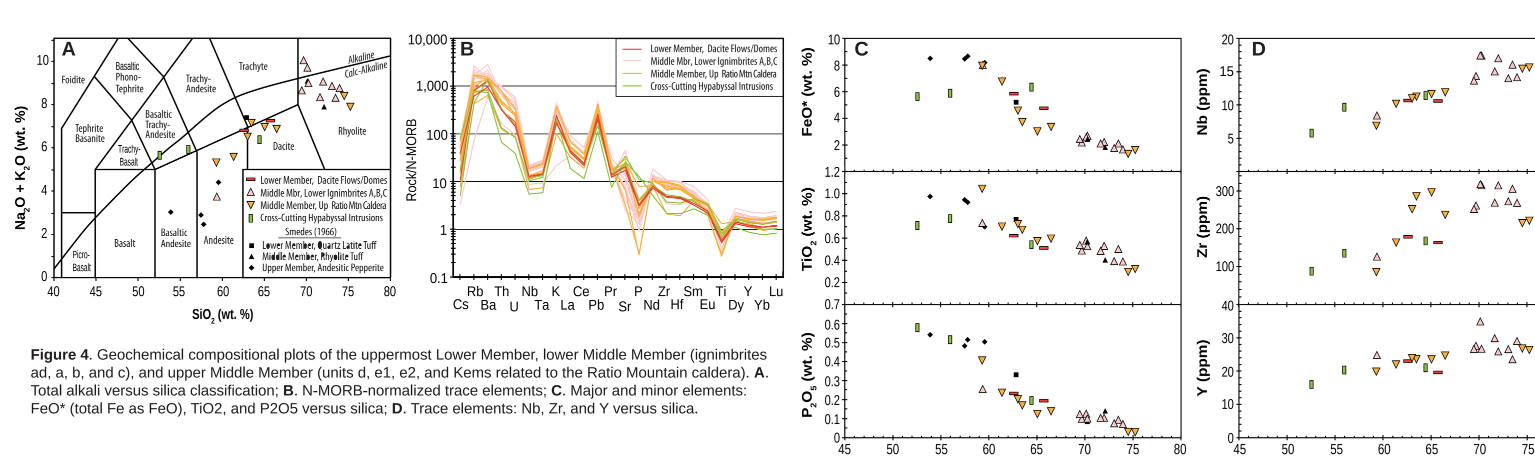


Figure 4. Geochemical compositional plots of the uppermost Lower Member, lower Middle Member (ignimbrites ad, a, b, and c), and upper Middle Member (units d, e1, e2, and Kems related to the Ratio Mountain caldera). **A**. Total alkali versus silica classification; **B**. N-MORB-normalized trace elements; **C**. Major and minor elements: FeO* (total Fe as FeO), TiO2, and P2O5 versus silica; **D**. Trace elements: Nb, Zr, and Y versus silica.

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