EDMAP 11

Geologic Map of the Mount Thompson 7.5' Quadrangle, Southwest Montana

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INTRODUCTION

The Mount Thompson 7.5′ quadrangle lies within the northeastern part of the Late Cretaceous Boulder batholith, where co-magmatic and calc-alkaline (Rutland et al., 1989) Elkhorn Mountains Volcanics (EMV) occur as one large (~65 km^2), and a few small (commonly ≤1.5 km^2) roof pendants (Fig. 1). An Eocene vent complex for the Lowland Creek Volcanics (LCV) (Smedes, 1962), a rhyolite ignimbrite of the Eocene-Oligocene (?) Avon Volcanics (see Mosolf, 2015), and Quaternary glacial gravels, till, landslides and alluvium also occur in the quadrangle. The area contains several historic Pb-Zn-Ag and Au-Ag mines. The largest production is from Late Cretaceous veins that occupy shear zones that cut the Boulder batholith and EMV. Eocene Au-Ag mineralization is disseminated and occurs associated with mineralized veins that exploited diatreme breccias related to the LCV vent complex at the Montana Tunnels open-pit mine. The area has moderate relief and includes the high-elevation Occidental Plateau of mixed grasslands and forest located at 7600 ft (2300 m) elevation in the northwest portion of the quadrangle, and to the south, forested ridges and canyons flanking the Boulder River at elevations as low as 5000 ft (1500 m).

PREVIOUS MAPPING

Brecraft et al. (1963) mapped the Jefferson City 15′ quadrangle at 1:48,000 scale and the Mount Thompson 7.5′ quadrangle occupies the SW ¼ of this map. Brecraft et al. (1963) described plutons of the Boulder batholith, mapped quartz and chalcedony veins and shear zones that host Late Cretaceous Ag-Pb-Zn mineralization, and examined the stratigraphy and structure of the EMV and LCV sequences. Sillitoe et al. (1985) described the nature of Eocene Au-Ag mineralization at the Montana Tunnels mine and described the host LCV diatreme breccia. The present study involved four man-months of fieldwork, and focused on refining stratigraphic and structural relationships in the EMV, and the LCV vent complex, in light of new petrographic, geochemical, geochronology, and hydrothermal vein studies.

GEOLOGIC SUMMARY

Late Cretaceous Elkhorn Mountains Volcanics

The EMV form a large roof pendant over Butte granite, the primary pluton by volume of the Boulder batholith. The roof pendant is exposed in the northern part of the Mount Thompson 7.5′ quadrangle and extends into neighboring quadrangles to the north and east (Fig. 1). The EMV includes Middle Member ignimbrites and Upper Member volcaniclastic sedimentary rocks that are approximately 360 m, and at least 180 m thick, respectively. A previous $^{40}Ar/^{39}Ar$ age of an upper Middle Member ignimbrite in the Ratio Mountain 7.5′ quadrangle (Fig. 1) yielded an age of 83.7 Ma (Olson et al., 2016). In the Mount Thompson 7.5′ quadrangle, the Middle Member ignimbrites and Upper Member sandstones are confined in age by crosscutting granite porphyry intrusions that yield a U-Pb zircon age of 83.2 ± 1.9 Ma (Fig. 2).

In the Mount Thompson 7.5′ quadrangle, Middle Member EMV consists of crystal-rich, fiammé-poor dacitic ignimbrite (Kem_1) and crystal-poor, fiammé-rich rhyolitic ignimbrite (Kem_2; Fig. 5A). Both ignimbrites are in contact with Butte granite locally, and three small (0.25 – 4.8 km^2) roof pendants of dominantly unit Kem_2 crop out along A-A′ and on the western edge of the quadrangle. The ignimbrites are characterized by eutaxitic texture with compaction foliation generally dipping to the east or southeast. The southern margin of the primary roof pendant is gently folded. Glass in the ignimbrites has been coarsely recrystallized to plagioclase, alkali feldspar, and quartz due to contact metamorphism during emplacement of Butte granite pluton. Metamorphic biotite occurs throughout the thickness of the ignimbrites. The lower dacitic ignimbrite is reversely zoned and varies in thickness due to an irregular intrusive contact with the Butte granite and reaches a maximum thickness of approximately 180 m. The upper rhyolite ignimbrite is normally zoned unlike all the rhyolitic ignimbrites mapped in the Ratio Mountain 7.5′ and Boulder East 7.5′ quadrangles (Fig. 1) (Olson et al., 2016; Scarberry et al., 2017) and has a relatively uniform thickness of approximately 180 m. Both ignimbrites are locally rheomorphically deformed with steeply dipping foliations in exposures east of the Comet ghost town and immediately south of the LCV vent complex, which suggests the presence of paleotopography prior to their emplacement. Collectively, the ignimbrites are moderately to strongly welded, contain modest to moderate fiammé, and contain mafic minerals that have been partially to completely altered to mixtures of chlorite, biotite, local actinolite, local epidote, hematite, and titanium oxides. Primary phenocrysts include plagioclase, biotite, pyroxene, amphibole, and trace oxides in the lower dacitic ignimbrite (Kem_1), but the mafic mineral assemblage in the upper rhyolitic ignimbrite (Kem_2) is poorly preserved with the exception of some primary biotite.

The Upper Member EMV overlies Middle Member ignimbrites and both sequences are in turn unconformably overlain by Eocene-Oligocene (?) volcanics. The EMV Upper Member has a minimum thickness of 180 m in the quadrangle. The Upper Member consists predominantly of massive to planar, thinly bedded and poorly- to moderately-sorted andesitic to dacitic volcaniclastic sandstones and siltstones (Fig. 5B) with relatively thin (<10 m) discontinuous lava flows and ignimbrites locally (unit Keut). One lenticular-shaped 10 – 60 m thick fiammé-rich, crystal-poor rhyolite ignimbrite intercalated with sandstones (Loc. 7) was analyzed for geochemistry. This sequence is slightly more enriched in HFSEs and REEs (Fig. 3B) compared to the Kem_2 rhyolite ignimbrite from the Middle Member, but is otherwise similar in bulk composition.

Middle and Upper Member EMV in the Mount Thompson 7.5′ quadrangle are high in alkalis (K and Na) and are metaluminous and calc-alkaline in composition, similar to exposures of these sequences in the Ratio Mountain (Olson et al., 2016) and Boulder East (Scarberry et al., 2017) 7.5′ quadrangles (Fig. 3C). Like in the Ratio Mountain and Boulder East quadrangles, these volcanic rocks are relatively enriched in large ion-lithophile elements (K, Rb, Sr, Cs, Ba, Rb) and Pb, which likely reflects assimilation of crustal rocks enriched in these elements. The Kem_1 ignimbrite has a characteristically neutral Eu anomaly whereas the Kem_2 ignimbrite has a moderate negative Eu anomaly, more similar to the Upper Member sandstones and ignimbrites (Fig. 3A). Both the Middle Member ignimbrites are unlikely correlative with ignimbrites described in the Ratio Mountain 7.5′ quadrangle (Olson et al., 2016) based on differences in compositional zoning and trace element geochemistry. Furthermore, it is unclear how well the ignimbrites and sedimentary rocks in the Mount Thompson quadrangle correlate with EMV ignimbrites located further northeast, and east of the quadrangle that have yielded younger U-Pb zircon ages of approximately 82 Ma to 76 Ma (Ihinger et al., 2011). Ignimbrites younger than those described in the Mount Thompson 7.5′ quadrangle would necessarily be located higher in the stratigraphic section.

Late Cretaceous plutons of the Boulder batholith

In the Mount Thompson 7.5′ quadrangle, the Boulder batholith consists of older porphyritic granite satellite intrusions hosted by EMV roof pendants and younger Butte granite, alaskite, and aplite intrusions. A U-Pb zircon age determined by SHRIMP-RG for an older granite porphyry plug that crosscuts unit Keus near the Mount Washington mine (Loc. 8) yielded one of the oldest known ages for satellite intrusions related to the Boulder batholith (83.2 ± 1.9 Ma; Fig. 2B).

The main body of the Butte pluton consists of medium- to coarse-grained biotite-hornblende granite. Brecraft et al. (1963) differentiated Fe-Ox-stained granite from unaltered medium and fine-grained granite, which are grouped together in this compilation. A few satellite stocks of Butte granite occur in EMV roof pendants. The mapped extent of aplite and alaskite dikes is adopted from Brecraft et al. (1963).

Eocene Lowland Creek Volcanics

The LCV erupted between approximately 49 Ma to 53 Ma (Dudás et al., 2010) and unconformably overlie Late Cretaceous rocks of the Boulder batholith and EMV regionally. The LCV are up to 1 km thick regionally. The volcanic pile consists of dacite lava flows, pyroclastic breccias, domes, and two regionally extensive rhyolite ignimbrites. Known LCV pyroclastic vents include the Big Butte vent complex located in Butte, Montana (Smedes, 1962; Proffett et al., 1982; Dresser, 2000; Dudás et al., 2010; Houston and Dilles, 2013; Scarberry et al., 2015), and an associated diatreme at the Montana Tunnels mine (Sillitoe et al., 1985).

New mapping in the Mount Thompson 7.5′ quadrangle suggests that the Montana Tunnels diatreme (1 km^2; Sillitoe et al., 1985) may be a late-stage feature of a larger (≥11 km^2) pyroclastic vent complex, which is larger than the ~6 km^2 northwest-elongate vent complex preserved at Big Butte that trends towards Bull Run Creek (Houston and Dilles, 2013). We herein refer to the vent complex in the Mount Thompson 7.5′ quadrangle as the “Spring Gulch vent complex” because Spring Gulch occurs along the northern boundary of the vent within the Mount Thompson quadrangle (see map). Comet Creek similarly lies along the southern boundary of the vent. New $^{40}Ar/^{39}Ar$ age determinations of early intracaldera dacitic tuffs and crosscutting late dacitic dikes indicate that the Spring Gulch vent complex formed at approximately 51.9 Ma (Fig. 2A), and suggests that the vent complex formed relatively rapidly. The ages from the Mount Thompson 7.5′ quadrangle overlap within analytical uncertainty of the age of the LCV Upper Tuff and rhyodacite intrusive rocks at the Big Butte vent complex (Dudás et al., 2010). The Big Butte vent complex and Springs Gulch vent complex are ~50 km apart, and although the Upper Tuff at the Big Butte vent complex and the intracaldera tuffs (unit Tltd) at the Spring Gultch vent complex are likely sourced from their respective vents, they are coeval and share similar geochemical compositions. In Fig. 2A, sample 00-24 (Upper Tuff) from Dudás et al. (2010) may alternatively be related to the pyroclastic rocks in the Mount Thompson 7.5′ quadrangle because it lies roughly equidistant between the recognized LCV pyroclastic vents at Big Butte and Spring Gulch.

In the Mount Thompson 7.5′ quadrangle, the ~11 km^2 Spring Gulch vent complex is elongated from southwest to northeast for at least 6 km and is ≤2.25 km in width. The vent complex continues along strike for another ~1.8 km into the adjacent Chessman Reservoir, Jefferson City, and Wickes 7.5′ quadrangles. The Spring Gulch vent complex is hosted in the main 65 km^2 roof pendant of the Late Cretaceous EMV. Here, clasts of Butte granite and EMV are commonly entrained in Eocene LCV pyroclastic rocks; particularly the diatreme (unit Tldb) at the Montana Tunnels mine. Dacitic intrcaldera tuffs and air-fall deposits (unit Tltd; Loc. 9, 10, 11) along the margins of the Spring Gulch vent complex are in excess of 60 m thick and locally cap pyroclastic rocks (unit Tlpr) in the central portion of the vent complex. Intracaldera tuffs occur on the margins of the vent and are lithic-rich with abundant fiammé near the base, and lithic- and fiammé-poor higher in the section. Locally, measured compaction foliations from the LCV tuffs define synclinal features that suggest vent collapse during the waning stages of the eruption. The walls of the vent are steeply dipping, cut across topography at a high angle, and flare outwards locally, where large blocks of EMV are down-dropped, or perched, on the vent margin and rotated inward towards the vent. On the north wall of the pit at Montana Tunnels (Loc. 10), the intracaldera tuffs are particularly lithic-rich, and compositionally depleted of HREEs similar to some late dacite dikes (unit Tlib; Loc. 15) that contain trace garnet of uncertain origin. The intracaldera tuffs appear to be intruded locally by early dacite dikes of a similar composition (Loc. 12). Late fissure-like bodies of pyroclastic rocks also crosscut the overlying intracaldera tuffs along shared contacts, particularly along the southwest vent margin.

The bulk of the central portion of the vent complex is composed of rhyolitic pyroclastic rocks (unit Tlpr) that are crystal-rich and strongly winnowed of ash or glass, where any remnant glass has been completely devitrified, and lithics (usually <2 cm) are rare. These pyroclastic rocks have a large abundance of subhedral or broken quartz and plagioclase crystals, and deformed biotite in an ash-poor, crystal-rich matrix (Fig. 5L). The matrix is comprised of finer broken crystal fragments, and lesser rock fragments. Dacitic airfall deposits (unit Tltd) cap the pyroclastic vent rocks (unit Tlpr) locally. The pyroclastic rocks (units Tlpr, Tlpx, Tldb) are geochemically evolved relative to the associated dacitic counterparts (units Tltd, Tldi, Tlib, Tlih) (Fig. 3), probably due to a matrix that has been strongly winnowed away during eruption.

The rhyolitic pyroclastic rocks are subdivided into two subunits: Tlpx and Tldb. Tlpx occurs on the vent margins and is characterized by strongly indurated and prominent outcrops (Fig. 5I-J). The sequence is also characterized by rip-up clasts of primarily dacitic units (Tldi and Tltd). Unit Tldb correlates with the diatreme breccia of Sillitoe et al. (1985) at the Montana Tunnels mine. Tldb is matrix-supported with a steeply dipping and aligned flow fabric, and up to 30% polylithic clasts that range in size from <1 cm to 1 m in length. The diatreme exhibits steeply dipping walls that crosscut unit Keus on its western margin, a lithic-rich variant of unit Tltd on its northern margin, and likely units Tlpr or Tlpx on its southern and eastern margins (described as a crystal-rich tuff by Sillitoe et al., 1985). Late-stage dacitic hypabyssal dikes crosscut the early dacitic intracaldera tuffs, the rhyolitic pyroclastic rocks, and the diatreme breccia.

Eocene-Oligocene (?) Avon Volcanics

A ~10 m thick rhyolitic ignimbrite occurs in the middle of the Mount Thompson 7.5′ quadrangle (Loc. 17) where it unconformably overlies Upper Member EMV deposits. The rhyolite ignimbrite is compositionally like ignimbrites found approximately 35 km northwest in the Avon 7.5′ quadrangle (Trombetta and Berg, 2012; Mosolf, 2015), and like those mapped by Brecraft et al. (1963) approximately 9 km north in the Chessman Reservoir 7.5′ quadrangle at Red Mountain. Mosolf (2015) reported a U-Pb zircon age of 40.8 ± 0.17 Ma for rhyolite tuff in the Avon 7.5′ quadrangle, and ages that span as young as ~30.0 Ma for basaltic andesite volcanic rocks in the Gravely Mountain 7.5′ quadrangle northwest of Avon and Elliston.

The ignimbrite in the Mount Thompson 7.5′ quadrangle has elevated HREE compositions and large negative Eu anomalies (Fig. 3A). The ignimbrite, like those described in the Avon 7.5′ quadrangle, is highly differentiated, depleted in most compatible trace elements and LILE (particularly those enriched in plagioclase and alkali feldspar), and is strongly enriched in some HFSE such as Y, Nb, and Ta, and some incompatible elements such as Rb, U, and Th (Fig. 3B).

Structure, Veins, and Mineralization

The EMV and Boulder Batholith formed in the late Cretaceous during the waning stages of Mesozoic Cordilleran arc magmatism, and concurrent with fold and thrust belt deformation in western Montana (Tilling and others, 1968; Rutland and others, 1989). Granite porphyry intrusions (Kgp) formed in the Mount Thompson 7.5′ quadrangle at approximately 81Ma to 83 Ma, or about 5 Ma to 7 Ma earlier than emplacement of the Butte pluton (Kbg) at around 76 Ma (Fig. 2). Molycorp discovered low-grade porphyry Cu-Mo mineralization in the northwestern map corner immediately north of the Mount Washington mine (Sillitoe et al., 1985), and where the older granite porphyry intrusions (Kgp) are clustered (see map). These observations suggest that the older granite porphyry intrusions (Kgp) may have produced Cu-Mo mineralization in the quadrangle. Hydrothermal muscovite from Pb-Zn-Ag veins formed shortly after emplacement of the Butte Granite (Fig. 2).

High-angle oblique reverse faults crosscut the Butte granite and EMV with minimal offsets in the southeast corner of the Mount Thompson 7.5′ quadrangle (see map). These structures host aplite dikes, high-temperature quartz –sulfide ± tourmaline veins (Fig. 5F), sulfide-poor low-temperature vuggy quartz, chalcedony, and minor carbonate veins (Fig. 5D), and multiple episodes of hydrothermal breccias (Fig. 5E). Quartz-chalcedony±carbonate veins and hydrothermal breccia forms prominent silica rib outcrops along the high-angle structures. Stereonet plots of poles-to-planes of both quartz veins and silica ribs (Fig. 4) reveal a primarily east-west trend for late Cretaceous mineral vein orientations (Fig. 4). The quartz veins are typically associated with Pb-Zn-Ag mineralization and are characterized by local tourmaline-bearing veins and hydrothermal breccia zones, which transition to quartz-sulfide veins and breccia that contains pyrite, sphalerite, galena, and traces of chalcopyrite or arsenopyrite. Low-temperature quartz-chalcedony-carbonate veins are locally associated with low-grade uranium mineralization in the southern portion of the quadrangle (e.g., Free Enterprise Radon Health mine).

The Eocene LCV erupted from a northeast-southwest trending corridor during the onset of regional normal faulting, extension, and core-complex formation (Constenius, 1996; Dudás et al., 2010). LCV diatreme breccia (Tldb) contains Au-Ag-Pb-Zn mineralization at the Montana Tunnels mine, where the mineral deposits form sericitically-altered stock work veins and are disseminated in the diatreme breccia (Tldb) (Sillitoe et al., 1985).

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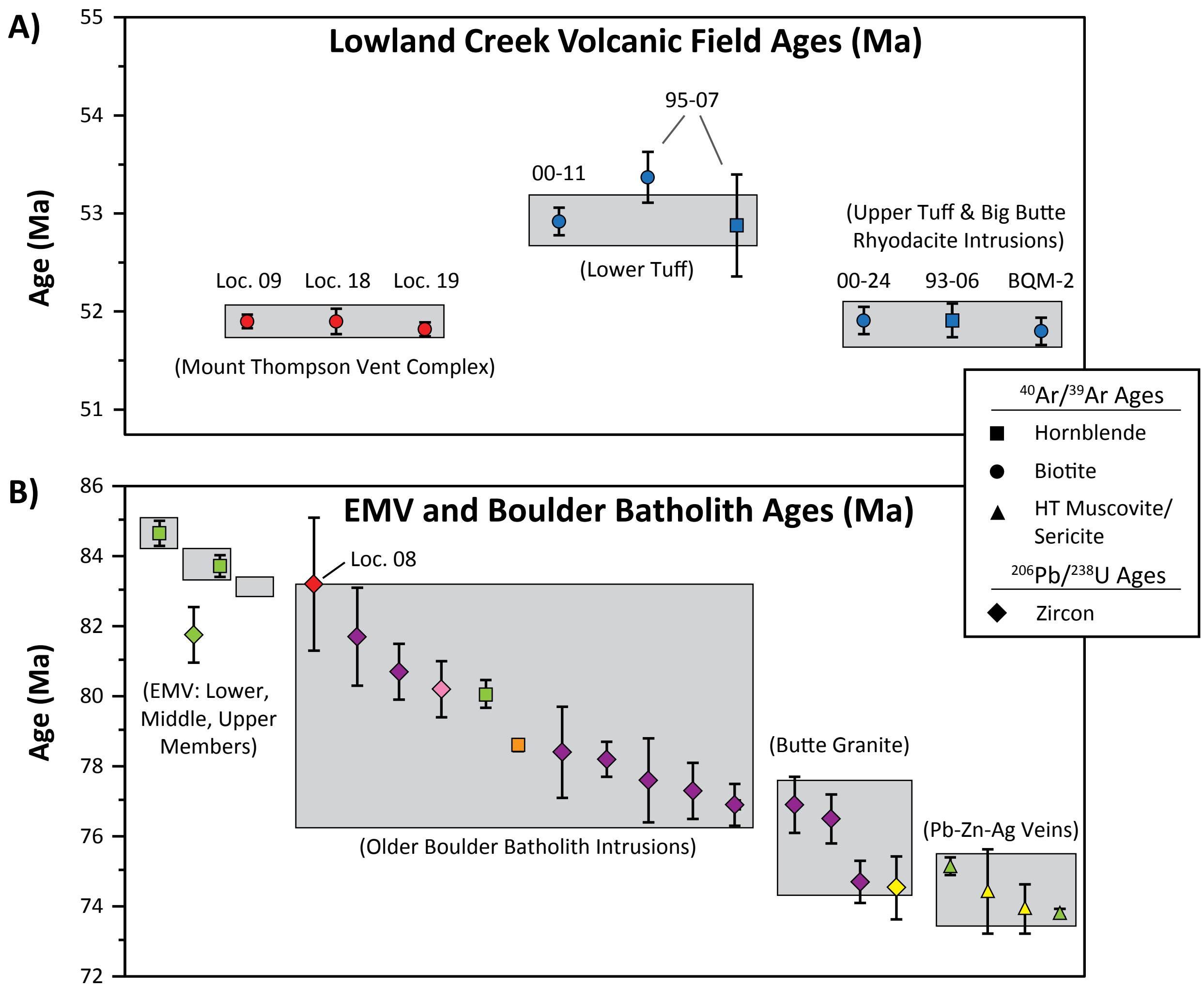


Figure 2. Geochronology of **A)** the Lowland Creek Volcanic Field, and **B)** the Elkhorn Mountain Volcanics (EMV) and the Boulder Batholith. Symbol colors are red Red (Mount Thompson quadrangle); blue (LVC in Butte North 1:100,000 from Dudás et al., 2010); green (Ratio Mountain quadrangle) and orange (Wilson Park quadrangle) from Olson et al. (2016); purple from Du Bray et al. (2012), pink (Boulder East quadrangle) from Scarberry et al. (2017); and yellow from Lund et al. (2002) (including ages of hydrothermal muscovite from the Eva May and Hope-Billion mines from within the Mount Thompson quadrangle). Besides the work of Dudás et al. (2010) and Lund et al. (2002), all reported $^{40}Ar/^{39}Ar$ ages are unpublished weighted mean plateau ages from the OSU Geochronology Laboratory by D. Miggins, J. Blessing, T. Horton, and J. Dilles. ^{207}Pb-corrected $^{206}Pb/^{238}U$ zircon ages are unpublished data from the Stanford-USGS SHRIMP-RG laboratory by N. Olson and J. Dilles, except for those data reported by Du Bray et al. (2012) and Lund et al. (2002).

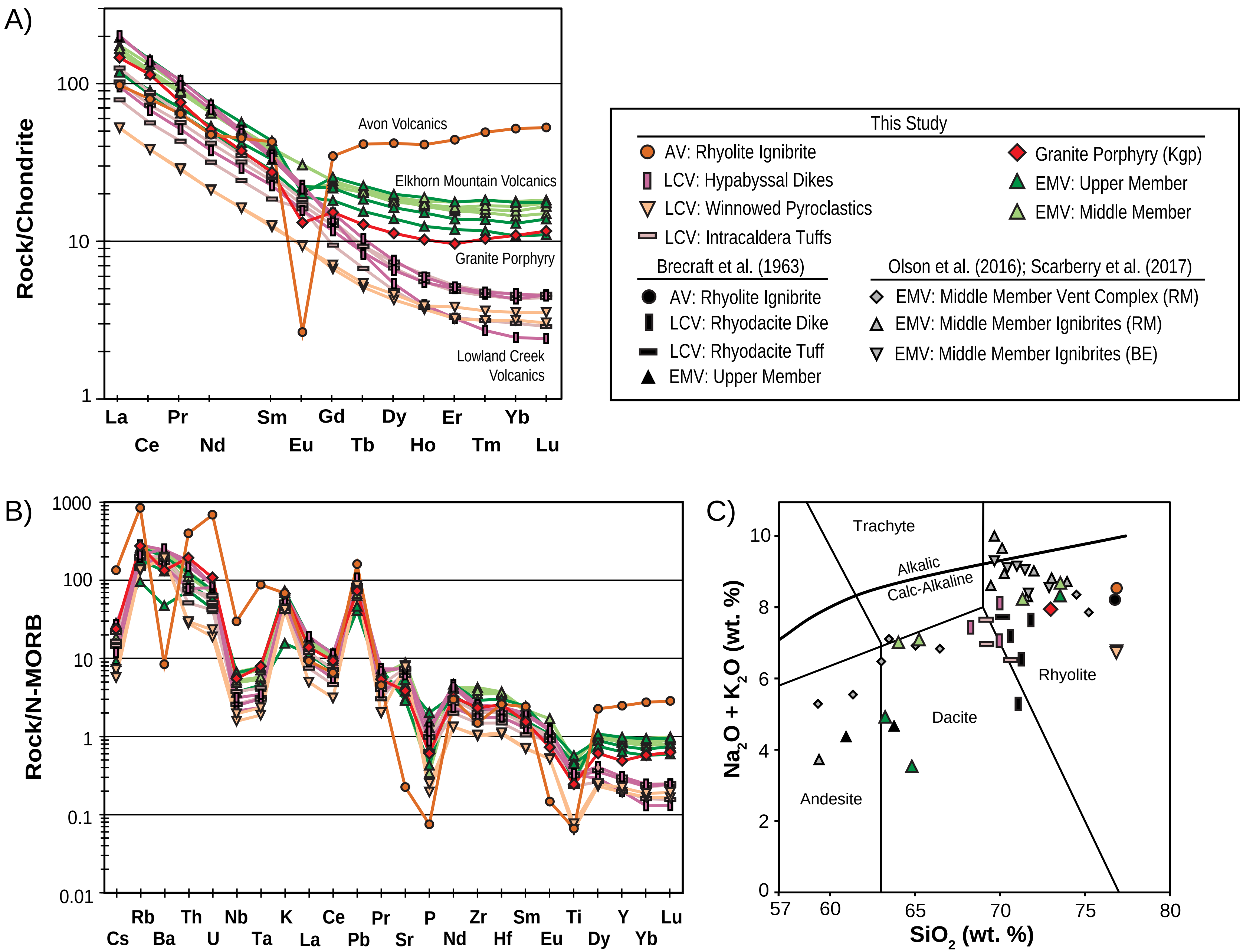


Figure 3. Geochemistry of Cretaceous and Eocene rocks in the Mount Thompson quadrangle. A) Chondrite-normalized rare earth element compositions (McDonough and Sun, 1995); B) N-MORB normalized trace element compositions (Sun and McDonough, 1989); C) Total alkalis versus silica classification diagram.

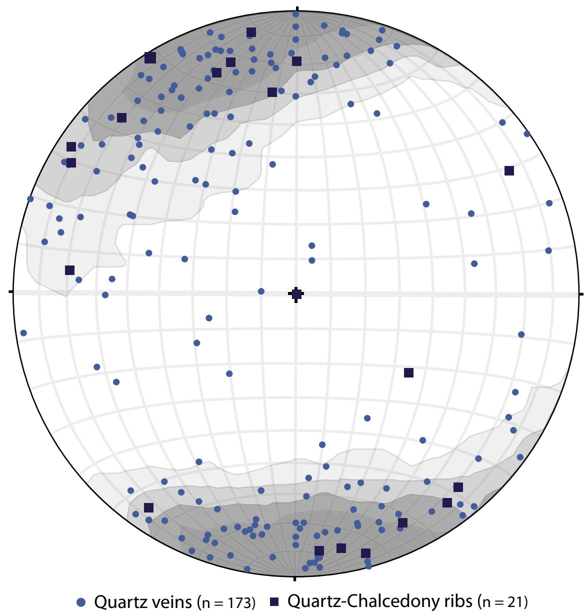


Figure 4. Equal-area, lower-hemisphere stereonet projections of poles-to-planes for quartz veins and quartz-chalcedony ribs in the Mount Thompson quadrangle. All poles are Kamb-contoured using a contour interval of 2σ and a counting area of 1.9% of the net area.

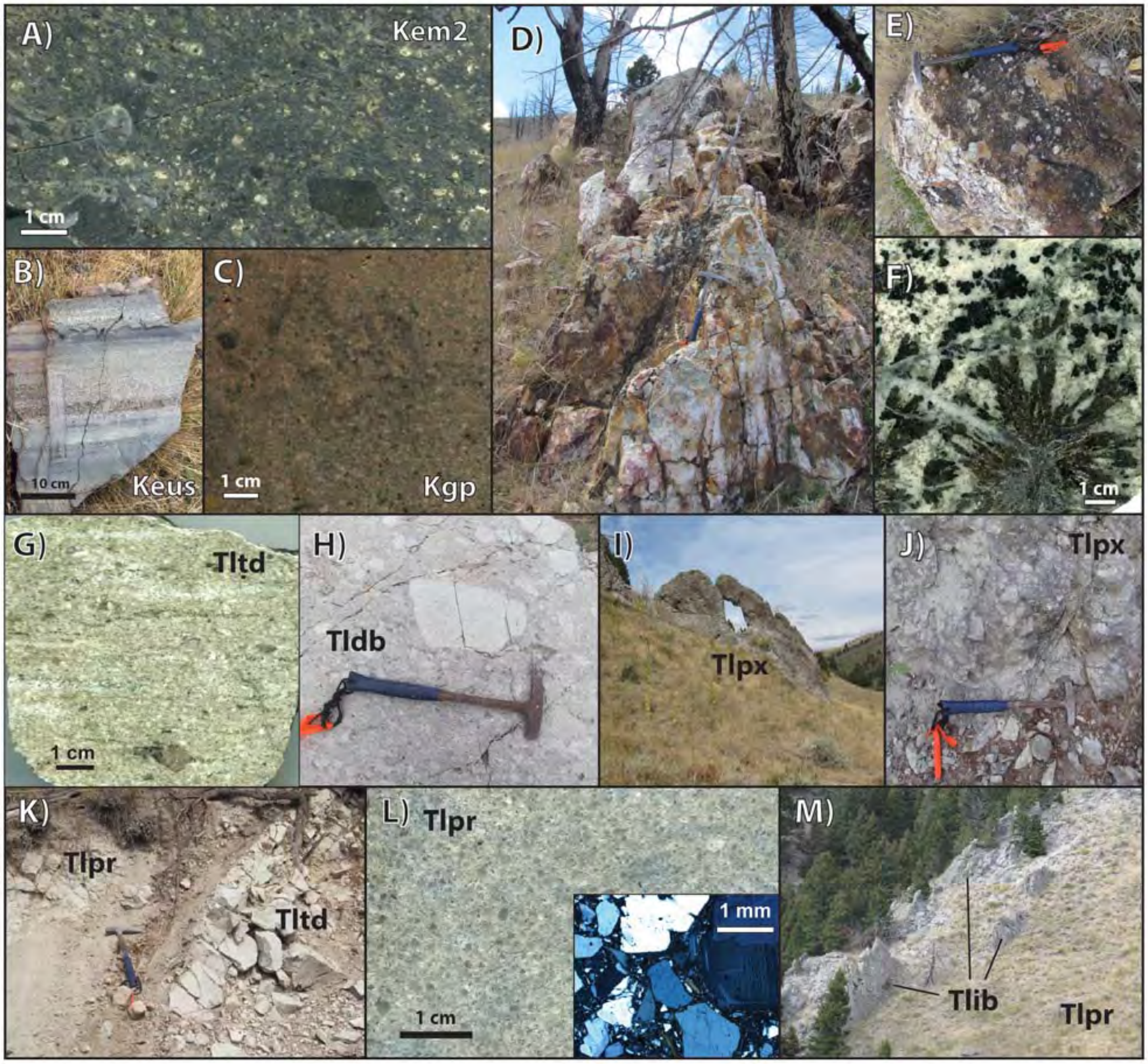
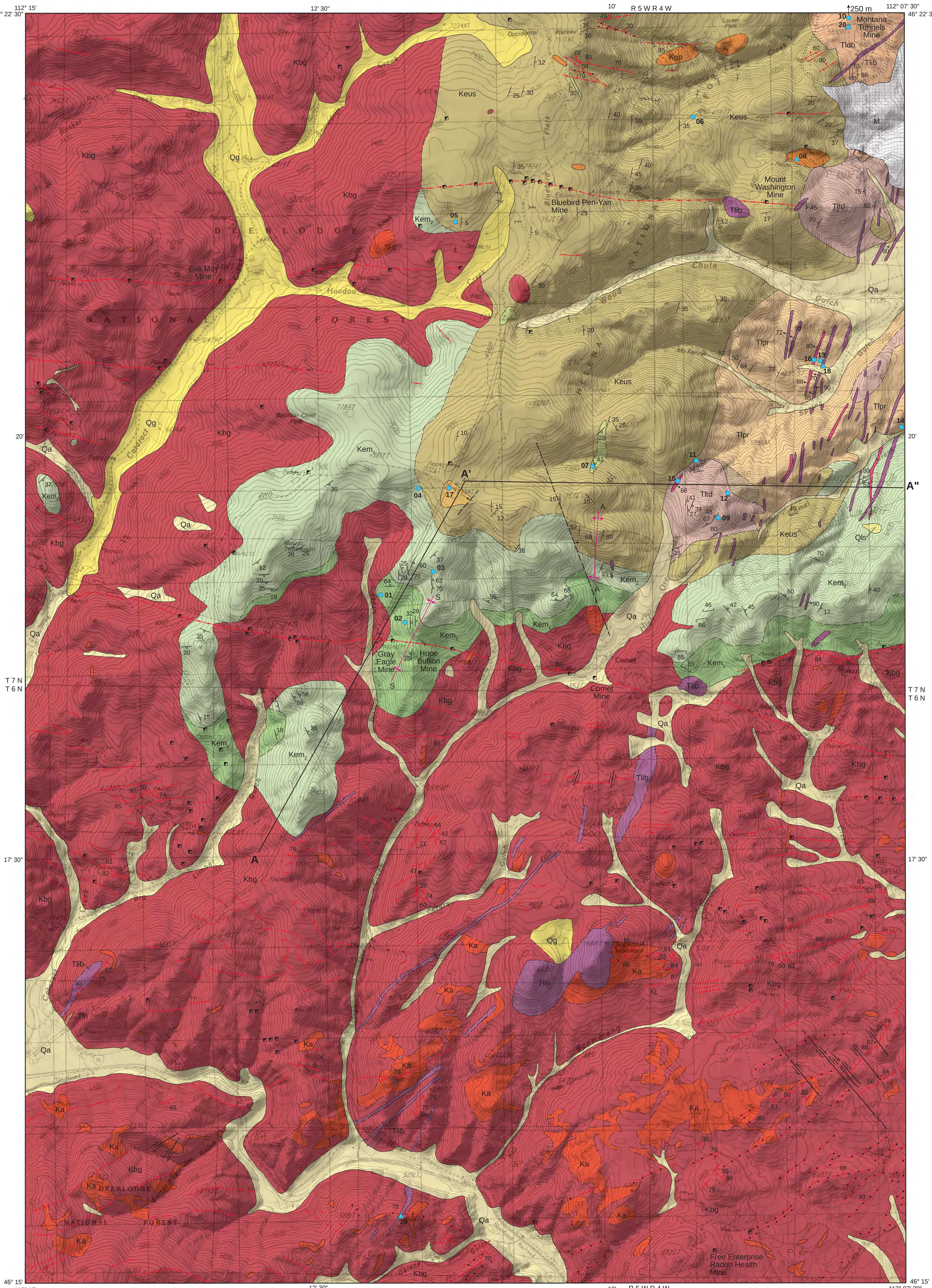


Figure 5. Field photos and photomicrographs from the Mount Thompson quadrangle. **A)** Middle Member ignimbrite (Kem2) of the Elkhorn Mountain Volcanics (Loc. 03); **B)** normally-graded laminar beds of sandstone and siltstone (unit Keus); **C)** granite porphyry (unit Kgp) that cross-cuts unit Keus (Loc. 05); **D and E)** prominent quartz vein outcrop and associated hydrothermal breccia hosted in the Butte granite; **F)** tourmaline-quartz-albite-pyrite altered host rock from the Bluebird-Pen Yan mine; **G)** intracaldera tuffs of the Lowland Creek vent complex located on the north wall of the Montana Tunnels pit (Loc. 10); **H)** diatreme breccia; **I and J)** indurated pyroclastic breccias (unit Tlpx) forming prominent outcrops; **K)** fissure-like bodies of pyroclastic rocks (unit Tltr) that crosscut dacitic intracaldera tuffs (unit Tltd), **L)** photomicrographs of rhyolitic pyroclastic rocks (unit Tlpr) that are poorly indurated, crystal-rich and winnowed of matrix (see inset); and **M)** prominent outcrops of late dacitic hypabyssal dikes (units Tlib, Tlih) that crosscut the poorly-outcropping pyroclastic rocks (unit Tlpr).

Table 1. Major and trace element compositions of igneous rocks from the Mount Thompson quadrangle.

Elkhorn Mountain Volcanics: Lower Member					EMV: Upper Member			Grndio Ppy	Lowland Creek Volcanics Vent Complex								Avon Volc.
Lithology	Kem$_1$	Kem$_1$	Kem$_2$	Kem$_2$	Keus	Keus	Keut	Kgp	Tltd	Tltd	Tltd	Tldi	Tltr	Tltx	Tlib	Tlih	Trt
Sample ID	NHO16-92	NHO16-93	NHO16-94	NHO16-96	NHO16-98	NHO16-99	NHO16-85	NHO16-25	NHO16-05	NHO16-08	NHO16-40	NHO16-41	NHO16-86	NHO16-28	NHO16-03	NHO16-81a	NHO16-22
Location #	01	02	03	04	05	06	07	08	09	10*	11	12	13	14	15	16	17
SiO_2	63.05	64.36	72.50	69.24	63.76	59.47	72.36	71.58	66.93	66.91	67.95	66.27	75.43	75.61	67.70	66.95	74.07
TiO	0.637	0.594	0.334	0.432	0.724	0.566	0.348	0.309	0.412	0.290	0.397	0.401	0.082	0.096	0.397	0.402	0.081
Al_2O_3	18.19	17.98	14.43	15.53	13.60	13.46	14.21	13.98	15.31	15.73	15.59	15.48	13.51	13.47	15.35	14.83	12.30
FeO*	3.40	2.99	1.46	2.01	6.77	5.79	1.63	2.21	2.71	1.58	2.31	2.55	0.63	0.77	1.91	2.18	1.03
MnO	0.061	0.051	0.020	0.045	0.141	0.111	0.052	0.032	0.027	0.033	0.026	0.040	0.012	0.016	0.015	0.047	0.083
MgO	1.24	1.07	0.32	0.72	3.81	4.48	0.37	0.76	1.82	0.85	1.47	1.90	0.19	0.22	1.51	1.62	0.08
CaO	4.82	4.47	0.91	1.02	5.85	5.33	1.20	1.36	2.65	3.09	2.85	3.10	1.62	1.58	1.85	2.78	0.56
Na_2O	3.41	3.39	3.24	2.93	2.35	1.51	2.91	2.94	3.37	3.30	3.70	3.61	3.60	3.54	3.22	2.88	3.46
K_2O	3.49	3.60	5.31	5.05	1.12	3.12	5.27	4.85	3.36	2.87	3.80	3.60	3.04	3.07	4.63	3.88	4.76
P_2O_5	0.152	0.125	0.040	0.082	0.237	0.183	0.050	0.071	0.116	0.075	0.114	0.102	0.023	0.029	0.149	0.130	0.008
LOI (wt.%)	0.74	0.74	0.91	2.00	0.94	5.18	0.70	1.16	2.58	4.54	1.03	2.37	0.99	0.87	2.60	3.38	3.05
Ni	3	3	2	3	18	50	2	7	22	6	17	24	0	0	26	19	4
Cr	7	4	4	4	70	148	4	12	73	17	49	84	4	4	45	34	3
Sc	10	9	5	7	20	16	6	6	7	4	6	6	2	1	5	4	3
V	66	54	22	32	176	139	24	36	45	27	43	45	7	8	35	42	3
Ba	1175	1301	1454	1366	299	819	1223	828	1030	1165	1227	945	1211	1173	1501	1547	55
Rb	98	102	147	143	54	101	150	155	108	80	114	112	74	76	156	120	477
Sr	792	706	276	347	418	477	260	350	538	647	672	559	730	697	653	688	19
Zr	282	308	255	280	158	156	209	170	129	111	150	131	76	78	185	167	109
Y	23	25	25	24	21	18	28	13	8	5	9	8	5	6	6	9	70
Nb	11.9	12.2	15.8	13.9	8.5	8.7	14.9	12.7	6.2	6.0	8.6	6.1	3.6	4.7	4.8	6.7	70.2
Ga	19	20	14	17	16	16	15	13	20	20	21	22	17	18	23	20	22
Cu	5	3	1	2	11	24	2	3	8	4	11	9	1	2	8	7	2
Zn	53	53	37	44	74	60	37	258	64	54	54	59	23	28	57	50	48
Pb	19	21	27	24	12	14	25	23	26	23	27	26	24	26	29	33	50
La	36	36	37	39	32	26	43	34	26	17	29	26	11	14	45	44	21
Ce	69	74	78	76	57	52	81	68	43	34	55	37	22	26	84	84	51
Th	10	11	16	13	9	11	15	23	8	6	10	9	4	4	21	18	48
Nd	28	28	29	27	25	21	31	22	18	11	21	17	9	11	30	30	22
U	3	4	3	4	3	3	3	3	3	2	2	3	1	1	3	4	30

Analyses by XRF at the Geoanalytical Laboratory at Washington State University, 2017, unnormalized. * indicates the sample is located 250 m north of the edge of the quadrangle.



Base map produced by the United States Geological Survey
Mount Thompson 1:24,000-scale quadrangle map
Control by: USGS and NOS/NOAA
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°52' West
1988 Magnetic NorthDeclination: 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.

N

SCALE 1:24,000

1 1/2 0 1 MILE

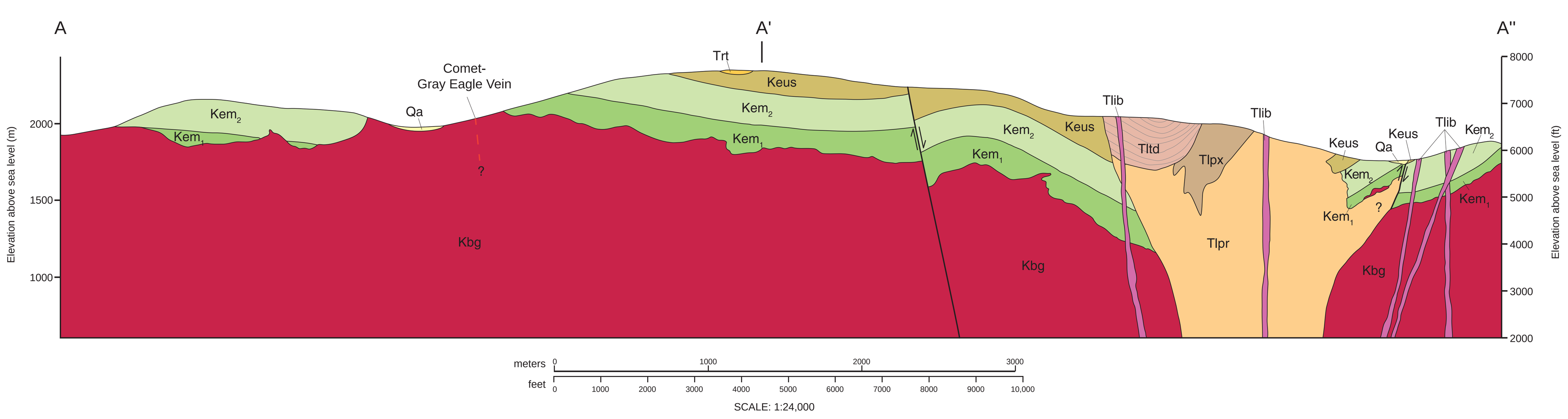
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 .5 0 1 KILOMETER

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://mbmg.mtech.edu

Cross Section A–A'–A"



Olson, Sepp, Mankins, and Blessing received student research support from the USGS EDMAP program. This map and explanatory information is submitted for publication with the understanding that the United States Government is authorized to reproduce and distribute reprints for governmental use.
Research supported by the U.S. Geological Survey, National Cooperative Geologic Mapping Program, under assistance Award No. G16AC00207.

GIS production: Christopher P. Smith, MBMG. Map layout: Susan Smith, MBMG.

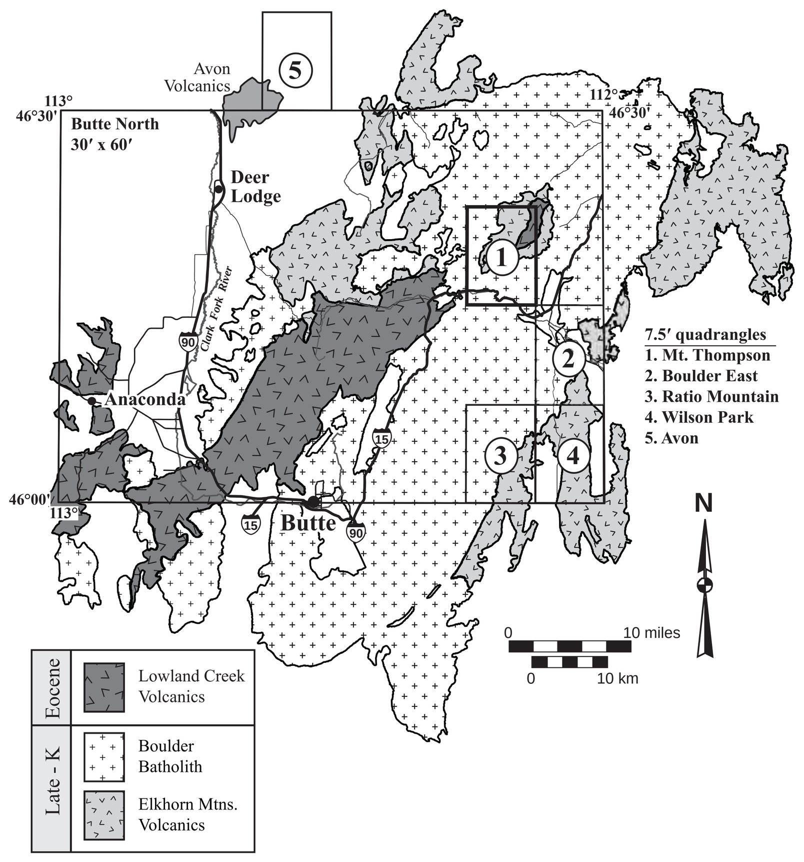
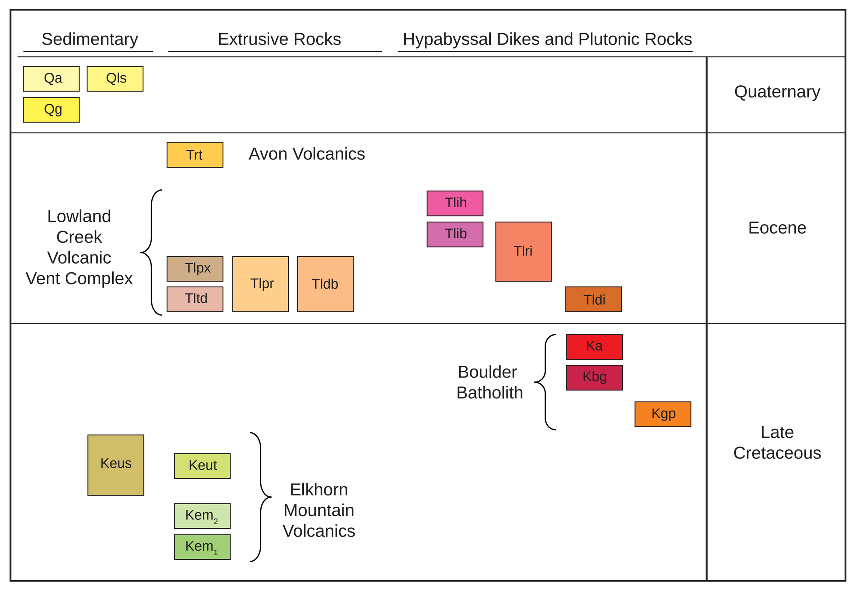


Figure 1. Location map. Geology after Vuke and others, 2007.

CORRELATION DIAGRAM



MAP SYMBOLS

- Contact: dashed where approximately located
- Gradational contact
- Fault: dashed where approximately located, dotted where concealed
- Normal fault: dashed where approximately located, dotted where concealed, bar and ball on downthrown side
- Syncline: showing trace of axial plane
- Anticline: showing trace of axial plane
- 84 — Quartz veins that show sulfide minerals; arrows indicate dip maginitude and direction
- 86 — Silica ribs; arrows indicate dip maginitude and direction
- 38 — Strike and dip of inclined sedimentary bedding and pyroclastic flow banding
- 40 — Strike and dip of inclined compaction foliation
- 85 — Strike and dip of inclined rheomorphic foliation
- Historic mine adit
- Historic mine shaft
- 12 — Geochemical sample Location (see Table 1 in pamphlet and references within map text)
- 09 — Isotopic Age Location (see Figure 2 in pamphlet)
- M — Modified; Montana Tunnels mine dump

UNIT DESCRIPTIONS

SEDIMENTS

Qa Quaternary alluvium, colluvium, and talus deposits.

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

Qg Quaternary-Holocene glacial gravels (glacial till and fluvial deposits) adopted from Brecraft et al. (1963).

IGNEOUS AND VOLCANIC ROCKS OF THE AVON AND LOWLAND CREEK VOLCANICS (EOCENE)

Avon Volcanics

Trt Pinkish white to gray crystal-rich (30–35 vol. percent) rhyolite ignimbrite with abundant fiammé (2–5 vol. percent). Only recognized in a single locality within the quadrangle. Unit is poorly to moderately welded, approximately 10–20 m thick with a ≥1 m thick basal vitrophyre (Loc. 17). Phenocrysts (<1 mm) include dominantly untwinned feldspars including sanidine and albite (?), quartz, biotite, and trace plagioclase with albitic twinning. Mosolf (2015) reports U-Pb zircon ages that range from approximately 30 Ma to 48 Ma for volcanic rocks near Avon (Fig. 1).

Lowland Creek Volcanics, Related Intrusions, and Deposits

Tlri White hydrothermally altered rhyolite porphyry dikes with 35 vol. percent crystals and 65 vol. percent microcrystalline aplitic groundmass (0.02–0.05 mm). Phenocrysts include coarse plagioclase (≤7 mm), quartz (1–5 mm), and biotite (≤2 mm). Plagioclase is completely hydrothermally altered to sericite or illite, and primary biotite is partially altered or replaced by coarse muscovite and/ or sericite. These dikes are found striking northeast in the southwest corner of the quadrangle and in the dumps of the Mount Washington Mine.

Tlih Medium-gray crystal-poor dacite dikes with abundant amphibole and subordinate biotite (Loc. 16). These dikes are commonly less-affected by vapor-phase alteration. Locally, they crosscut Tlib dikes, intracaldera tuffs and airfall tuffs (Tltd), and pyroclastic rocks (Tlpr, Tlpx, Tldb). They contain 15–25 vol. percent crystals in a microcrystalline (0.05 mm) groundmass. Crystals include plagioclase (1–2 mm; 10–15 vol. percent); amphibole (1–8 mm; 5–10 vol. percent), biotite (≤2 mm; <8 vol. percent); sanidine (2–5 mm; 1–2 vol. percent), and accessory magnetite and apatite. The abnormally high abundance of amphibole and biotite relative to plagioclase is also characteristic of unit Tldi.

Tlib White, tan, or pink crystal-rich dacite dikes with abundant biotite (biotite >> hornblende), a microcrystalline groundmass (0.05 mm), and commonly vapor-phase altered, sometimes with 0.5 cm lithophysae. Locally, they crosscut units Tltd, Tlpr, Tlpx, and Tldb. The abundance of phenocrysts range from 20–30 vol. percent with coarse euhedral plagioclase (1–6 mm; 25–45 vol. percent), quartz (1–4 mm; 2–4 vol. percent), and zoned sanadine and anorthoclase (1–5 mm; ≤0.5 vol. percent), and fine-grained biotite (≤2 mm; 5–10 vol. percent), amphibole (≤0.3 mm; ≤1 vol. percent), and accessory magnetite and apatite. The groundmass consists of plagioclase, quartz, alkali feldspar, and biotite. Garnet xenoliths (≤0.5 cm) are sometimes found locally (Loc. 15). The large intrusion at Sugarloaf Mountain is a crystal-rich end-member with coarser plagioclase (up to 1 cm). It uniquely has up to 70 percent of its plagioclase with resorbed rims and sieved cores. Sanidine crystals are also resorbed locally. The groundmass is also uniquely fine (<0.02 mm) in comparison with other Tlib dikes although it is one of the largest Eocene intrusive bodies in the quadrangle.

Tldb Diatreme breccia exposed at the Montana Tunnels open-pit mine. This diatreme has been interpreted to be phreatomagmatic breccia based on recognition of a juvenile matrix to the breccia, incorporation of juvenile rhyolite porphyry and dacite porphyry into the breccia and locally crosscutting the breccia, a high matrix to fragment ratio, and the occurrence of subsided blocks of pyroclastic base surge deposits within the breccia (Sillitoe et al., 1985). The diatreme includes heterolithic subanglular to well-rounded clasts (up to ~30 vol. percent) of Elkhorn Mountain Volcanic sandstones (Keus), Butte Granite (Kbg), lithic-rich dacite tuffs (Tltd), crystal-rich rhyolitic pyroclastic rocks (Tlpr), and dacitic to rhyolitic porphyries (Tlib, Tlri) that range in size from large blocks near the margins to most commonly <20 cm clasts towards the interior. The diatreme is matrix supported with a coarse "sandy" crystal-rich matrix of broken angular quartz and feldspar crystals, biotite, and rock fragments (all 0.25–1 mm; ~50–70 vol. percent), and lesser rock flour and carbonate cement (~10–20 vol. percent). On the southern pit wall, a subvertical flow fabric of the diatreme is observed. Primary biotite in clasts and the matrix has been altered nearly completely to chlorite, sericite, or coarse muscovite (~0.5 mm). Muscovite, sericite, and illite also completely replace plagioclase in clasts and matrix where hydrothermally altered. Fine 1–2 mm quartz-pyrite-galena veins are observed with 1–2 mm muscovite replacing whole clasts, biotite, and feldspar crystals in the vein selvage. Pyrite (0.25–1 mm) also occurs disseminated in the vein selvages. Late calcite veins crosscut the quartz veins locally. Lastly, veined clasts with disseminated sulfides occur within the breccia, and sulfides also occur disseminated within the matrix suggesting episodic brecciation accompanying mineralizaiton (Sillitoe et al., 1985).

Tlpx Gray strongly indurated rhyolite pyroclastic rocks similar in composition to Tlpr. These breccias locally form prominent outcrops (Fig. 5c, Loc. 14) compared to Tlpr. Contains abundant (20–40 vol. percent) angular fragments of predominantly Tltd and Tldi, and lesser Kbg, Kem1, Kem2, and Keus. This unit is found as narrow zones 1 to 30 m wide near the contact of Tltd along the southern vent margins. The overall chemical composition and characteristics of the matrix is similar to that of Tlpr. The matrix is crystal-rich with 20–30 vol. percent angular quartz (0.5–2 mm), 40–50 vol. percent subhedral to broken angular fragments of plagioclase (0.5–3 mm), 1–2 vol. percent biotite (0.5 mm), and 20–30 vol. percent microcrystalline biotite, quartz and clay after vapor-phase altered glass.

Tlpr Poorly-consolidated and poorly out-cropping, white to pinkish-white crystal-rich rhyolitic pyroclastic rocks with rare lithic fragments (<1 cm) (Fig. 5j-l). Primary glass has been winnowed away and remnant glass has been vapor-phase altered. Occurs primarily as massive bodies or locally as fissure-like bodies with a weak subvertical flow fabric. This is the primary lithology of the vent complex. The matrix is crystal-rich with 20–25 vol. percent anglular quartz (0.5–2 mm), 40–50 vol. percent subhedral to broken angular fragments of plagioclase and anorthoclase (0.5–3 mm), 2–3 vol. percent biotite (0.5 mm), and 10–20 vol. percent microcrystalline biotite, quartz and clay after vapor-phase altered glass.

Tldi Dark grey unaltered crystal-rich (60–65 vol. percent) hypocrystalline dacite dike or block hosted within unit Tltd (Loc. 12). Includes clasts of equigranular granite (possibly the Butte granite; <1 vol. percent) and a chlorite-altered biotite-hornblende-plagioclase-orthopyroxene-clinopyroxene unit (possibly a cumulate rock; 1–2 vol. percent). Primary phenocrysts are euhedral and preferentially aligned. The phenocrysts include plagioclase (30 vol. percent; 0.5–2 mm), biotite (20 vol. percent; <0.5 mm), amphibole (3–5 vol. percent; <1 mm), quartz (≤0.5 vol. percent; <1 mm), and trace apatite <0.5 mm. Primary plagioclase is normally zoned and primary amphiboles have zoned rims. A subordinate population of plagioclase contains sieved and resorbed textures, and a subordinate population of amphibole is chlorite-altered suggesting both likely originate from the altered xenoliths. Quartz is also strongly resorbed suggesting it may be a xenocrystic phase.

Tltd Reddish-brown to tan welded crystal-rich dacite intracaldera tuffs and airfall deposits. These tuffs occur commonly on the margins of the vent complex and cap unit Tlpr locally. Near the base of the intracaldera tuffs, fiammé (approximately 1–2 vol. percent) and heterolithic clasts are most-abundant (up to 5 vol. percent) . Fiammé and lithics are rare or absent higher in the section. Fiammé commonly are 1–3 cm with aspect ratios ranging from 3 to 5. Near the base of the tuffs at the southwestern end of the vent, lithics range in size from 1–5 cm commonly, and up to a maximum of approximately 1 m diameter. Along the north and northeast walls of the Montana Tunnels open pit (e.g., Loc. 10), the dacitic tuffs are particularly lithic-rich with heterolithic clasts. Locally, these tuffs are crosscut by late-stage calcite veins and biotite is pervasively altered to chlorite. The mineralogy and crystal abundance of the tuffs is similar to Tldi dikes. The tuffs contain 30–35 vol. percent subhedral to angular fragments of plagioclase crystals (0.5–1 mm), 8–10 vol. percent biotite (0.5 mm), 2–3 vol. percent hornblende (0.5 mm), and 1–2 vol. percent quartz (0.3 mm) in a devitrified glass (50–55 vol. percent) recrystallized to microcrystalline quartz, biotite, and feldspar. Plagioclase associated with lithic clasts commonly have resorbed rims and sieved cores. Amphibole and clinopyroxene associated with some lithic clasts have been partially altered to actinolite, chlorite, and epidote likely prior to entrainment.

CRETACEOUS VOLCANICS, INTRUSIONS, AND RELATED DEPOSITS

Boulder Batholith

Ka Alaskite bodies and aplite dikes are medium- to fine-grained and contained with subequal proportions of quartz, K-feldspar, and plagioclase. Mapping of alaskite and aplite dikes hosted within the Butte granite are adopted from Brecraft et al. (1963).

Kbg Butte granite, includes fine- to medium-grained hypidiomorphic-equigranular granite consisting of plagioclase, K-feldspar up to 1 cm long, and quartz, with 15 to 20 vol. percent mafics that include biotite, hornblende, and accessory magnetite, titanite, apatite, ilmenite, and zircon. Granite is in contact with units Kem1, Kem2, and Keus of the Elkhorn Mountain Volcanics, and is crosscut by dacitic dikes of the Lowland Creek Volcanics (Tlib). U-Pb zircon age determinations for the Butte granite yield a range of ages between 64.5–66.5 Ma (Fig. 2), but a preferred age of approximately 66.5 is supported by some Ar-Ar ages of ~65.1 Ma for hydrothermal muscovite from Pb-Zn-Ag veins hosted in the Butte granite in the Ratio Mountain quadrangle (Fig. 2).

Kgp Porphyritic granite intrusions (83.2±1.9 Ma, U-Pb zircon, SHRIMP-RG). Includes porphyritic granitic dikes or plugs hosted in unit Keus near the Mount Washington mine (Loc. 08) and Bluebird Pen-Yan mine with ~50–60 vol. percent phenocrysts, and 40–50 vol. percent interstitial quartz and K-feldspar with granophyric and graphic textures. Phenocrysts include 45 vol. percent plagioclase (1–4 mm), 5 vol. percent chloritized biotite (≤2 mm), 2–4 vol. percent magnetite (≤0.5 mm), 1–2 vol. percent hornblende (~1 mm) altered entirely to hydrothermal biotite and chlorite, 1–2 vol. percent poikilitic-textured K-feldspar (2–5 mm), 0.5 vol. percent quartz (0.1–0.5 mm), and accessory apatite and zircon. Plagioclase phenocrysts commonly have sieved cores and contain inclusions of biotite.

Elkhorn Mountains Volcanics and Volcaniclastic Deposits

Upper Member

Keut Laterally discontinuous dark gray ash flow tuffs or ignimbrites up to 35 m thick that are intercalated within Keus sandstones. Locally, they contain abundant fiamme (up to 5 vol. percent; 3–5 cm) and have vitroclastic and eutaxitic textures (Loc. 7). Crystallinity varies, but generally these tuffs have poor to moderate crystal contents (10–20 vol. percent). Mafic sites are commonly altered completely to chlorite or epidote, but igneous biotite textures are evident. Geochemically, the ignimbrite at Loc. 7 is rhyolitic compared to the host andesitic to dacitic sandstones.

Keus Dark grey, reddish-brown, or dark green massive to thinly-bedded volcaniclastic sandstones, siltstones, and relatively thin (<10 m) discontinuous sequences of ash flow tuffs. Unit unconformably overlies unit Kem[2]. Sedimentary rocks range in composition from andesitic to dacitic (Fig. 3), and are poorly sorted with normal- and reversely-graded planar bedding. Sandstone contains clasts of volcanic lithics, plagioclase, and altered pyroxene and hornblende. Pyroxene and hornblende are partially to completely replaced by chlorite, and lesser epidote. Metamorphic biotite occurs near the unconformable contact with Kbg.

Middle Member

Kem_2 Dark grey, maroon, or black normally-zoned crystal-poor strongly-welded dacitic ignimbrite. This ignimbrite conformably overlies ignimbrite Kem1. It contains 15–25 percent crystals of plagioclase (0.5–2 mm; 15 vol. percent) and trace K-feldspar (1–2 mm). Mafic sites (0.5–1 mm; 3–5 vol. percent) are nearly completely replaced by chlorite and muscovite, but probably originally consisted of biotite ±clinopyroxene, ±hornblende. Fiammé are moderately abundant, particularly towards the base of the ignimbrite (≤5 vol. percent; up to 10 cm; aspect ratios of 3–5x). The abundance of fiammé is a distinguishing characteristic compared to unit Kem1. Eutaxitic and vitroclastic textures are commonly observed. Fiammé and glass are typically coarsely recrystallized to quartz, biotite, and feldspar (≤0.2 mm) and metamorphic biotite is observed throughout the unit. The ignimbrite is locally rheomorphically deformed with stretched fiammé (>10:1 aspect ratios).

Kem_1 Dark grey, maroon, or black reversely-zoned crystal-rich strongly-welded dacitic ignimbrite. The lower exposures of this ignimbrite are intruded by the Butte granite. The ignimbrite contains 35–50 percent crystals of plagioclase (0.5–3 mm; 30–40 vol. percent), orthopyroxene/clinopyroxene (0.3–0.5 mm; 3–5 vol. percent; 1:2 ratio), hornblende (1–2 vol. percent; <0.5 mm), biotite (1–2 vol. percent; <1 mm), and trace K-feldspar (1–2 mm). Fiamme are sparse (<1 vol.) and smaller (commonly 2–3 cm) compared to Kem2. Fiamme and glass are commonly coarsely recrystallized to quartz, biotite, and feldspar (≤0.2 mm) and metamorphic biotite is observed throughout the unit.

For a more detailed description of the map and the references used please refer to the text accompanying this map.

MBMG
Montana Bureau of Mines and Geology

MBMG EDMAP 11

Geologic Map of the Mount Thompson 7.5' Quadrangle, Southwest Montana

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2017

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