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Preliminary Geologic Map of the Red Ridge Area, Churchill and Mineral Counties, Nevada

by

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ABSTRACT

The Walker Lane accommodates dextral motion between the northwest translating Sierra Nevada microplate to the west and Basin and Range extension to the east. A significant portion of dextral shear in the central Walker Lane is accommodated on left-stepping, en echelon, northwest-striking fault systems that compose the Walker Lake domain. Northwest of these dextral faults, strain is transferred to sinistral faults accommodating oroclinal flexure and clockwise-rotation of blocks in the Carson domain of the northern Walker Lane. Positioned at the northern terminus of the Walker Lake domain, the Red Ridge area resides southeast and in right-lateral separation across the Benton Spring fault from the Terrill Mountains. The thick Oligocene to late Miocene volcanic strata of the Red Ridge area provide opportunity to examine Tertiary strata and styles of deformation and correlate to results of recent geologic mapping completed in the adjacent Terrill Mountains quadrangle. Detailed geologic mapping of the Red Ridge area was completed to help elucidate the Neogene styles of, and transitions in, strain accommodation for this region of the Walker Lane.

Geologic mapping of the Red Ridge area greatly elucidated the stratigraphic and structural framework of Red Ridge and expanded understanding of deformation at the northern termination of the Walker Lake domain. The Tertiary strata included late Oligocene ash-flow tuffs and Miocene volcanic rocks correlated to, and dextrally offset from, Terrill Mountains stratigraphy. Several ash-flow tuffs correlate with regionally extensive units and provide opportunity for future paleomagnetic study. Similar to the southern Terrill Mountains, northeasterly-striking normal faults appear kinematically linked to major northwest-striking dextral faults and accommodate diffusion of dextral strain and basin development. The detailed mapping of the Red Ridge area has provided a firm foundation for future structural analysis and paleomagnetic study of the region.

INTRODUCTION

The Walker Lane resides directly east of the translating Sierra Nevada microplate and at the western boundary of Basin and Range extension. The Walker Lane accommodates ~20% of the dextral motion between the North American and Pacific plates (figure 1; e.g., Atwater and Stock, 1998; Bennet et al., 2003; Kreemer et al., 2009). This dextral motion is accommodated within structural domains characterized by discontinuous systems of dextral, sinistral, and normal faults (e.g., Stewart 1988, Faulds and Henry, 2008). At the transition between the central and northern Walker Lane, strain is transferred from systems of northwest-striking dextral faults of the Walker Lake domain to east-northeast-striking sinistral faults and oroclinal flexure accommodating clockwise vertical-axis rotation of crustal blocks in the Carson domain (figure 1; e.g., Stewart, 1988; Cashman and Fontaine, 2000; Faulds and Henry, 2008). At the northern terminus of the Walker Lake domain the Terrill Mountains and Red Ridge structural blocks are separated in a right-lateral sense across the inferred northernmost segment of the Benton Spring fault (figure 1B). Recent geologic mapping of the Terrill Mountains quadrangle documented a distinct and localized paleosol dextrally offset ~6 km across the Benton Spring fault (Carlson, in press), consistent with minimum displacement observed on segments to the southeast (Ekren and Byers, 1984).

To further understanding of strain accommodation and transfer at the northern terminus of the Walker Lake domain, detailed geologic mapping (1:24,000 scale) of the Red Ridge area was completed. Positioned directly east of dextral faults observed in the Terrill Mountains quadrangle, mapping of the Red Ridge area is used to help elucidate the structural development and characteristics of faulting at the northernmost segment of the Benton Spring fault.

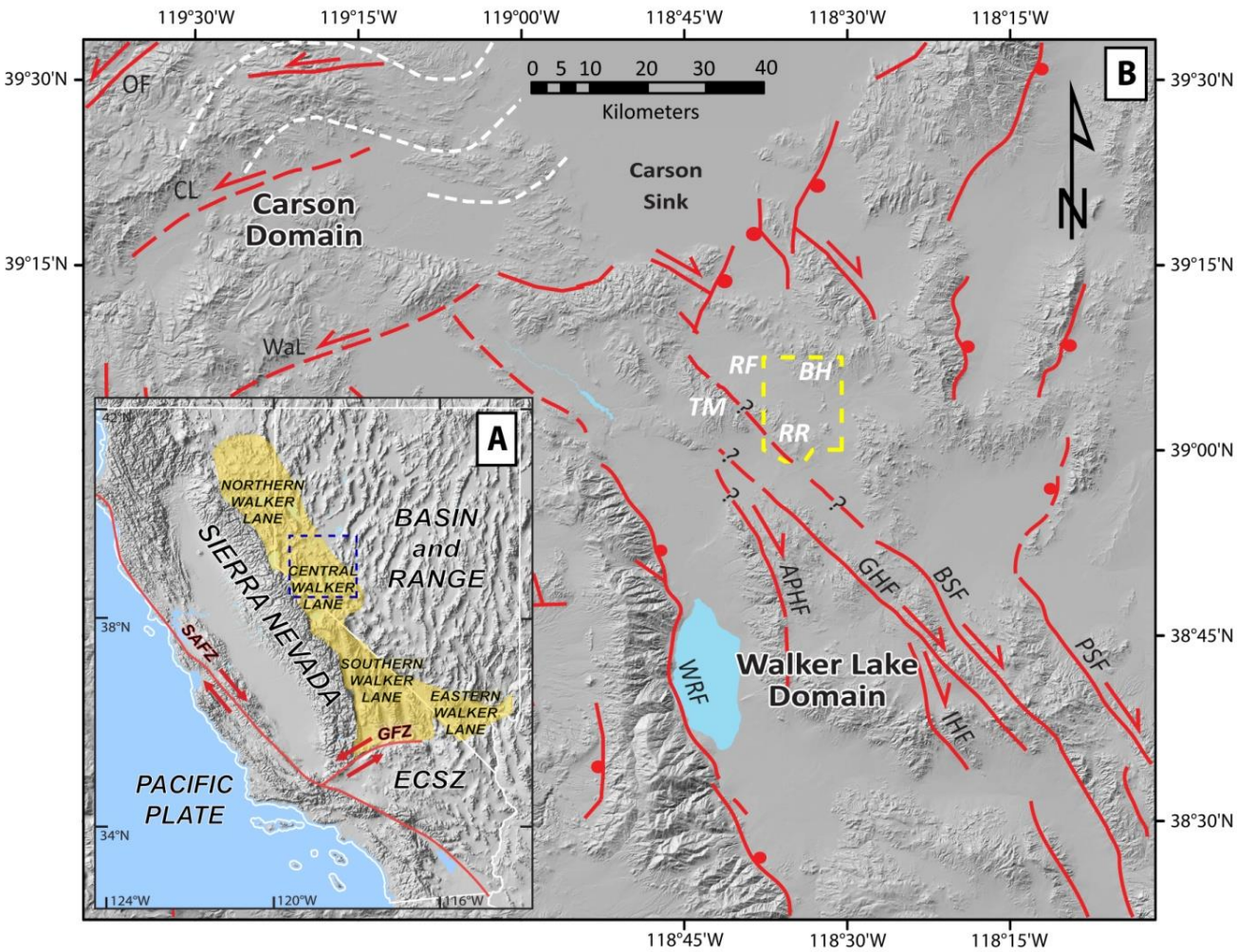

Figure 1. A: Shaded-relief map depicting a portion of western North America, modified from Carlson et al. (2013). Walker Lane shaded in yellow and divided into northern, central, southern and eastern portions. ECSZ, Eastern California Shear Zone; GFZ, Garlock fault zone; SAFZ, San Andreas fault zone. Blue dashed box shows approximate location of Figure 1B. B: Shaded-relief map of the Walker Lake (central Walker Lane) and Carson (northern Walker Lane) domains. Yellow dashed polygon shows location of Red Ridge area map. Major faults and lineaments in the central and northern Walker Lane are modified from Faulds and Henry (2008). Regional faults: APHF, Agai Pah Hills fault; BSF, Benton Spring fault; CL, Carson lineament; GHF, Gumdrop Hills fault; IHF, Indian Head fault; OF, Olinghouse fault; PSF, Petrified Springs fault; Wal, Wabuska lineament; WRF, Wassuk Range frontal fault. White dashed lines denote orocline of Faulds and Henry (2008). Physiographic regions: BH, Barnett Hills; RF, Rawhide Flats; RR, Red Ridge; TM, Terrill Mountains.

SUMMARY OF WORK PERFORMED

The Red Ridge area was mapped between late 2014 and early 2016 to identify additional offset markers or piercing points across the inferred northernmost strand of the Benton Spring fault and identify correlative stratigraphic sections between the Terrill Mountains and Red Ridge structural blocks (figure 1B). The map of the Red Ridge area also includes ~8 km^2 of the northern part of the Hu-Pwi Wash 7.5-minute quadrangle, where outcrops of bedrock were mapped. Geologic data collected in the field was mapped on 1:24,000 scale, color, stereographic air photos. Geologic map units are described based on outcrop characteristic, phenocryst assemblages, and textures of collected hand samples. Mineralogical descriptions of collected hand samples and thin sections from samples collected in the adjacent Terrill Mountains quadrangle were used for regional correlations and additional detailed description of mapped geologic units (Carlson, in press). Field data were compiled and digitized using Vr software by Cardinal Systems to produce a three-dimensional model of individual stereo-photo pairs in the map area. The digitized field map was then exported to ArcGIS 10.3.1 for final cartographic production and completion of cross sections.

STRATIGRAPHIC FRAMEWORK

Bedrock

The bedrock exposures in the map area consist of Tertiary volcanic and sedimentary rocks resting nonconformably on Mesozoic basement rock. The Mesozoic basement rocks, mapped as undivided, appear to be dominated by granitic rocks and are exposed in the footwall of northeasterly-striking normal faults in the central and southern parts of Red Ridge. At least seven individual Oligocene ash-flow tuffs are observed, with an additional unit representing localized alteration of some of these tuffs. The oldest identified ash-flow tuff in the Red Ridge area is the Guild Mine Member of the Mickey Pass Tuff (Tmp), resting nonconformably on Mesozoic basement. Attitudes of compaction foliations in stratigraphically lowest sections of the tuff, deposited on the early Cenozoic erosional surface, can vary wildly. An unidentified ash-flow tuff overlies the Mickey Pass Tuff in the Red Ridge area. Correlated to Ttu_2 in the Terrill Mountains quadrangle (Carlson, in press), this "unknown tuff 2" is also characterized by an abundance of lithic clasts. In the central portion of Red Ridge, south of cross section A–A′, Ttu_2 is in nonconformable contact with Mesozoic basement. Conformably deposited over Ttu_2 is a poorly- to moderately-welded section of ash-flow tuff correlated with Ttu_3 in the Terrill Mountains quadrangle (Carlson, in press).

Following an ~1.4 Ma hiatus in regional ash-flow tuff eruptions (Henry and John, 2013), the tuff of Gabbs Valley was deposited disconformably over older ash-flow tuffs in the Red Ridge area. Outcrops of the tuff of Gabbs Valley pinch-out in the central portion of Red Ridge near cross section A–A′. A discontinuous and relatively thin "unknown tuff 4" (Ttu_4) crops out conformably over the tuff of Gabbs Valley only in the northern part of Red Ridge. An "unknown tuff 5" (Ttu_5) disconformably overlies the tuff of Gabbs Valley, where "unknown tuff 4" does not crop out in the northern Red Ridge. Similar to the Terrill Mountains, the tuff of Toiyabe is the youngest Oligocene ash-flow tuff in the Red Ridge area. The disconformable contact between the tuff of Toiyabe and Ttu_5, where cropping out in the Red Ridge area, lacks the localized paleosol observed in the Terrill Mountains quadrangle (Carlson, in press). In the central and southern Red Ridge the tuff of Toiyabe rests disconformably over the tuff of Gabbs Valley.

Early Miocene lavas and volcaniclastic breccias rest on Oligocene ash-flow tuffs with no observed angular unconformity. These units are correlated to the lavas, lahars, and block and ash flows of the Brown Knob formation observed in the Terrill Mountains quadrangle based on similar volcanic clasts and mineral compositions (Carlson, in press). Most of the early Miocene basaltic lavas in the Red Ridge area correlate with the oldest lavas of the Brown Knob formation ($Tbka_1$) observed in the Terrill Mountains quadrangle based on mapped stratigraphic position below volcaniclastic conglomerates, breccias, and intercalated finer-grained gravels and sands (Tbkc). Several andesitic to basaltic lavas in the Red Ridge area that lack an exposed stratigraphic relationship with Tbkc are mapped as "Brown Knob formation, undivided" and may correlate with younger Brown Knob lavas observed in the Terrill Mountains (e.g., outcrops in the southeastern portion of the map area). The youngest basaltic lavas (Tb) in the Red Ridge area commonly rest in angular unconformity on older lithologies. Owing to their greater resistance to erosion compared to underlying ash-flow tuffs, several outcrops of these younger basalts cap local topographic highs in the area. Bedrock exposures of volcanic rock not field checked in the eastern half of the Red Ridge area are mapped as "volcanic rock, undivided" (Tvu).

Quaternary Sediments

Quaternary sediments in the Red Ridge area consist of alluvial (coarse sands to gravels), lacustrine (silts, fine sands, and gravels), and eolian deposits (fine to medium sands). Most of the map area consists of expansive sheets of fine sand with isolated, and potentially remanent, sand dunes in some locations. These eolian deposits mantle the oldest alluvial fans and bedrock surfaces (Qafe) forming isolated exposures of outcrop in the Red Ridge area. The oldest alluvium (QTaf) in the Red Ridge area consists of alluvial fan sediments draped over bedrock in the northern portions of Red Ridge. These oldest fans are located within steeper topography than younger alluvial-fan units and may range in age from late Pliocene (?) to middle Pleistocene. Late Pleistocene fans (Qaf_1) are limited to a few fan remnants in the northern Red Ridge. These fans lack the draped silt and sand of late Pleistocene fans in the Terrill Mountains and are distinguished from younger fan units based on development of fan surfaces and their position above inset post-late Pleistocene alluvial fans (e.g., Qaf_2). The youngest alluvial fans (Qafy) are inset below older fans and are active depositional surfaces in the Red Ridge area.

Pleistocene silt and fine sand are common in the lowest topographic areas of the Red Ridge area. These fine-grained sediments, and irregular deposits of well-rounded, coarse gravel and sand that form curvilinear bars following topographic contour, are mapped as lacustrine deposits (Ql) up to the elevation of the Lake Lahontan highstand (e.g., Reheis, 1999). The youngest Quaternary units consist of colluvium on steeper slopes and alluvium in active washes (Qa and Qay), eolian deposits (Qe and Qed), ephemeral playas (Qp), and anthropogenically-modified surfaces (Qx). Quaternary eolian units mapped in the Red Ridge area are likely associated with the fine-grained veneers formed as part of Qafe. Isolated eolian deposits (Qe) and sand dunes (Qed) reside in the northeast and southwestern parts of the map area.

STRUCTURAL FRAMEWORK

The Red Ridge area is characterized by multiple northeasterly-striking normal faults that dip to the southeast and accommodate westerly tilts of fault-bounded blocks. These faults are positioned between the northwest-striking Benton Spring fault to the west and inferred and mapped northwest-striking faults that bound the northeast flank of Red Ridge. Unlike the Benton Spring fault in the Terrill Mountains quadrangle (Carlson, in press), the fault trace through the southwest corner of the Red Ridge area appears to be obscured by eolian deposits. Northwest-striking faults along the eastern flank of Red Ridge are inferred to accommodate normal displacement, based on juxtaposition of younger hanging wall rock cropping out east of Mesozoic basement, and wrap westward around the northern end of Red Ridge to link with the normal fault bounding the northeast range front of the Terrill Mountains (Carlson, in press).

Evidence for the youngest faulting in the map area is limited to scarps mapped in oldest alluvial sediments (QTaf), located in the northeast part of Red Ridge. The fault scarps strike northeast and preserve ~2–3 m of normal offset. These scarps may be slightly wave modified, as they lie near the elevation of the Lake Lahontan highstand (e.g., Reheis, 1999). However, deposits of lacustrine sediments are not observed over the down-thrown block directly below the scarp face. If more recent faulting has occurred in the Red Ridge area, eolian deposits likely obscure offsets in younger sediments.

SUMMARY OF FINDINGS

Upon completion of detailed geologic mapping of the Red Ridge area, several important observations were noted. Preliminary results have correlated several Oligocene ash-flow tuffs and Miocene volcanic rocks in the Red Ridge area to rocks documented in the Terrill Mountains (Carlson, in press). Although volcanic stratigraphy in the Red Ridge area is similar to that in the Terrill Mountains, no sections or paleochannels where observed that could be clearly correlated across the Benton Spring fault to constrain dextral displacement. Northeasterly-striking normal faults are observed between the inferred and obscured trace of the Benton Spring fault and the northwest-striking normal fault bounding the eastern flank of Red Ridge. These normal faults, similar to northeasterly-striking normal faults observed in the southern Terrill Mountains (Carlson, in press), may kinematically link and/or act in concert to diffuse dextral shear at the terminating ends of northwest-striking faults in the northern Walker Lake domain.

The detailed geologic mapping in the Red Ridge area has provided additional data for use in elucidating the deformational history and mechanisms of strain transfer in the region. These data will ultimately be combined with additional geologic mapping and paleomagnetic study of regional volcanic rocks to identify and better understand the differing styles of dextral shear accommodation at the central and northern Walker Lane transition.

DESCRIPTION OF MAP UNITS

Quaternary Deposits

Anthropogenic deposits

Qx Anthropogenic deposits and altered surfaces (Holocene) Areas extensively disturbed and/or obscuring geologic units.

Eolian deposits

Qe Eolian sand deposits (Holocene) Deposits of moderately- to well-sorted, medium- to fine-grained sands that overlie bedrock and oldest alluvial-fan units. Deposits are not regionally extensive and primarily located on steep slopes; commonly not more than ~1–2 m thick.

Qed Sand dunes (Holocene) Deposits of well-sorted, medium- to fine-grained sand that form irregular and locally elongate dune fields in the topographically lowest and flattest areas. Dune heights range from ~1–5 m.

Qafe Alluvial-fans with veneer of sands and silts (Holocene to early Pleistocene) Veneers (<0.5 m) of moderately-sorted medium- to fine-grained sands and silts deposited on older fan surfaces (e.g., 'QTaf'). Underlying alluvial fans are several to tens of meters thick, where exposed.

Alluvial deposits

Qay Active alluvial channel and transported sediments (Holocene) Youngest, poorly-sorted, alluvial sediments, ranging in size from boulders to silt and deposited in intermittent washes and ephemeral stream beds; commonly less than ~1 m thick.

Qa Alluvium (Holocene) Short-travelled moderately-sorted sands to cobbles deposited on moderate- to gently-sloped surfaces; commonly less than ~1 m thick. Includes veneers of rockfall deposits on steep slopes that obscure underlying lithologies.

Qa/Ql Alluvium deposits over late Pleistocene lacustrine deposits (Holocene) Veneers of alluvium deposited on late Pleistocene lacustrine deposits; commonly less than ~0.5 m thick.

Lacustrine and playa deposits

Qp Ephemeral playa deposits (Holocene) Closed depressions with fine-grained sediments (fine sand-silt/clay); commonly less that ~0.5 m thick.

Ql Lacustrine deposits (late Pleistocene) Undivided offshore, nearshore, and onshore deposits of fine sand, silt and mud, and gravel bars composed of well-rounded sands, pebbles, and cobbles. Deposits range in thicknesses from less than ~0.5 m of onshore deposits to a few to tens of meters of near- and off-shore deposits.

Alluvial-fan deposits

Qafy Active alluvial-fan deposits (Holocene) Young, active alluvial-fan deposits consisting of poorly-sorted sands and subangular pebble to cobble, and locally boulder gravels inset into older alluvial-fan units; commonly less than ~1 m thick.

Qaf_2 Alluvial-fan deposits (Holocene) Alluvial-fan deposits consisting of poorly-sorted sands and subangular pebble to cobble, and locally boulder gravels inset into older alluvial-fan units. Fan surfaces have better developed desert pavement and varnish development than Qafy and lack onlapping late Pleistocene lacustrine sediments; commonly a few to several meters thick.

Qaf_1 Alluvial-fan deposits (late Pleistocene) Alluvial-fan deposits consisting of poorly-sorted sands and subangular pebble to cobble, and locally boulder gravels inset into older alluvial-fan units; commonly a few to several meters thick. Fan surfaces are commonly more dissected and have better developed desert pavement and varnish development than Qaf_2.

Qaf Alluvial-fan deposits, undivided (Holocene to late Pleistocene) Alluvial-fan deposits consisting of poorly-sorted sands and subangular pebble to cobble, and locally boulder gravels; commonly a few to tens of meters thick. Unit older than active alluvial fans (i.e., Qafy) but lacks field relations for relative age determination with other alluvial-fans.

QTaf Alluvial-fan deposits (middle Pleistocene to Pliocene) Alluvial-fan deposits consisting of poorly-sorted sands and subangular pebble to cobble, and locally boulder gravels. Well-developed desert pavement and varnish. Topographically higher than other alluvial fans and locally gently tilted in contrast to younger, essentially subhorizontal alluvial fans. Fan deposits range from a few to tens of meters thick.

TERTIARY ROCKS

Oligocene–Miocene volcanic and sedimentary rocks

Tb Basaltic lavas (late Miocene) Youngest aphanitic mafic lavas, less-commonly vesiculated. Intergranular groundmass of ~90–95% interstitial plagioclase laths (~0.1–0.3 mm), with ~5–10% olivine, commonly altered to iddingsite (~0.1–0.5 mm). Outcrops typically display platy joints along foliation planes, locally becoming undulatory at the base of flow where exposed; flows are up to ~50 m thick in the northern Red Ridge. Age: 5.79±0.06 Ma ($^{40}Ar/^{39}Ar$), based on sample from correlative unit in Terrill Mountains quadrangle (Carlson, in press).

Tbku Brown Knob formation, undivided (middle to early Miocene) Named for the highest peak in the Terrill Mountains, the Brown Knob formation consists of basaltic to andesitic lavas, conglomerates, and intercalated sedimentary rocks. Mapped as undivided in parts of the quadrangle, where exposures are poor or less distinct.

> **Tbkc Volcaniclastic conglomerates, breccias, and intercalated sedimentary rocks of Brown Knob formation (early Miocene)** Multiple poorly-sorted, matrix-supported conglomerates and clast-supported breccias of primarily andesitic and dacitic clasts, ranging in thickness from ~5–10 m. Conglomerates and breccias are intercalated with deposits of poorly-indurated, well- to moderately- sorted, medium-grained, volcaniclastic sandstone and well-rounded gravel beds that commonly display crossbedding; commonly ~1–2 m thick. Total unit thickness ~200–250 m in the northern Red Ridge.
>
> **$Tbka_1$ Oldest basaltic andesite lavas of the Brown Knob formation (early Miocene)** Dark gray to reddish-brown, aphanitic, basaltic to andesitic lavas commonly vesiculated and scoriaceous. Flattened and slightly stretched vesicles in some flows locally define flow foliation planes. These basal flows of the Brown Knob formation are thin (<5 m thick) and discontinuous, cropping out only in a few locations in the northern and eastern portions of Red Ridge.

Tvu Volcanic rocks, undivided (late Miocene to late Oligocene) Includes volcanic rocks interpreted from aerial photographs and not verified in the field; located in eastern portions of the map area.

Tertiary intrusions

Thai Hornblende andesite intrusion (early Miocene) Multiple elongate andesitic to dacitic intrusive bodies aligned with north-northwest-striking normal faults along the east side of Red Ridge. Light purplish-gray trachytic

groundmass, consisting of euhedral oligoclase laths (~0.1 mm); contains needle-like phenocrysts of subhedral to euhedral hornblende (~1–2%, 1–3 mm). Up to ~100 m thick.

Ti Plagioclase-hornblende intrusions, dikes, and sills (early Miocene) This regionally extensive unit intrudes Oligocene ignimbrites, units of the Brown Knob formation, and faults in the form of dikes, sills, and irregular-shaped massive bodies. Porphyritic with light gray, interstitial plagioclase groundmass; contains phenocrysts of subhedral bytownite (~20%, ~2–3 mm long), hornblende (~10%, ~2–7 mm), and biotite (~2–3%; 1–2 mm). The amounts of hornblende and biotite phenocrysts, and relative size of plagioclase phenocrysts, decrease near chilled margins and within relatively smaller volume intrusions. Crops out as dikes and sills up to ~50 m thick and as intrusive bodies up to ~250 m thick. Age: 22.67±0.15 Ma ($^{40}Ar/^{39}Ar$) based on correlative unit in Terrill Mountains quadrangle (Carlson, in press).

Oligocene ash-flow tuffs

Ttt Tuff of Toiyabe (late Oligocene) Light tan to reddish-brown, densely to moderately welded ash-flow tuff that contains phenocrysts of subhedral andesine (~5–10%, ~1–2 mm long), sanidine (~10%, ~1–2 mm), and euhedral biotite (~2–5%, 2–4 mm). Characteristics vary across map area. White and moderately flattened pumice fragments in lower sections of tuff contain ~1–2 mm long euhedral biotite. Decreasing amounts of pumice up-section are commonly <1–2 cm long and have a low flattening ratio, if flattened at all. The basal vitrophyre noted in the Terrill Mountains is not observed in the Red Ridge area; ~250 m thick. Age: 23.29±0.02 Ma ($^{40}Ar/^{39}Ar$) based on correlative unit in Terrill Mountains quadrangle (Carlson, in press).

Ttu_5 Unknown tuff 5 (late Oligocene) Light green to light tan poorly welded ash-flow tuff that contains phenocrysts of subhedral sanidine (~5–7%, ~1–2 mm long) and quartz (~2%, ~1 mm). Unit is typically devoid of pumice fragments, but some outcrops locally display a preferential parting plane parallel to foliation. Unit is only observed in the northern Red Ridge; may make up part of the altered tuff (Ttua) south of mapped outcrops. Up to ~100 m thick.

Ttu_4 Unknown tuff 4 (late Oligocene) Peach to purplish, moderately welded ash-flow tuff that contains phenocrysts of subhedral sanidine (~10–15%, 1–2 mm long), oligoclase (~5%, <1 mm), quartz (~10%, ~1 mm), and euhedral biotite (<1%, <1 mm). Unit contains abundant pumice fragments with increased ratios of flattening moving down section. Top of unit appears weathered and planar with a very clear and discrete contact with overlying unit. Weathered surfaces can appear lithophysal, where pumice fragments have eroded out. Only observed in Oligocene stratigraphy cropping out at the eastern edge of map area; <15 m thick and locally pinches out.

Tgv Tuff of Gabbs Valley (late Oligocene) Densely welded ash-flow tuff that contains phenocrysts of subhedral sanidine (~5%, ~1–2 mm long), andesine (<1%, <0.5 mm), quartz (~2–3%, ~0.5 mm), and biotite (~1–2%, ~1 mm), commonly containing abundant and highly stretched fiamme. Upper sections have less fiamme and are more purplish-brown. Unit pinches out in the central part of Red Ridge (e.g., near cross section A–A′) and is up to ~100 m thick in the northern and southern parts of Red Ridge. Age: 24.95±0.02 Ma ($^{40}Ar/^{39}Ar$) based on sample from correlative unit in Terrill Mountains quadrangle (Carlson, in press).

Ttu_3 Unknown tuff 3 (late Oligocene) Light tan to light pink and purple, poorly welded ash-flow tuff that contains phenocrysts of sanidine (~7–10%, ~1–2 mm), oligoclase (~7%, ~1 mm), quartz (~3–5%, ~1 mm), and euhedral biotite (~2–3%, ~1 mm). Mostly devoid of pumice, but where present are very small (~3–4 mm, long-axis) and moderately flattened. Unit is devoid of the extensive lithics present in 'Ttu_2' below. Part of this ash-flow tuff may correlate with the tuff of Elevenmile Canyon (Tec) mapped in the northwestern part of the Terrill Mountains quadrangle (Carlson, in press). Up to ~250–300 m thick in the central part of Red Ridge.

Ttu_2 Unknown tuff 2 (late Oligocene) Light-tan, poorly to moderately welded ash-flow tuff that contains phenocrysts of sanidine (~5–7 %, ~1 mm), oligoclase (~5%, < 1mm long), quartz (~5%, ~1mm), and biotite (trace). Unit is distinctive in the area in its abundance of lithic clasts (mostly volcanic and cryptocrystalline quartz clasts, upwards of several centimeters in length and composing up to ~20% of unit in some locations). Small (~2–3 cm) devitrified fiamme are present in moderately welded sections. Up to ~300 m thick in the central part of Red Ridge.

Tmp Mickey Pass Tuff (late Oligocene) Pink to reddish-pink and purple, densely to moderately welded ash-flow tuff that contains variable percentages of phenocrysts (~15–25%) of subhedral sanidine (~5–10%, ~1 mm long), oligoclase (~1%, <1 mm), quartz (~10%, ~1–2 mm), and biotite (~2–3%, ~1 mm). White, flattened pumice fragments ranging from 5–30 mm long and 2–10 mm thick. Up to ~300 m thick in the central part of Red Ridge. Age: 27.1–27.4 Ma (Henry and John, 2013).

Ttua Undivided tuff, altered (late Oligocene) Used for ash-flow tuff units, commonly more poorly welded sections (e.g., Ttu_5 and Ttu_3), in the north-central part of Red Ridge, where early Miocene intrusions (e.g., Ti) have altered tuffs and obscured contact relationships.

PRE-TERTIARY ROCKS

Mzu Mesozoic basement granitic and metamorphic rocks, undivided (Mesozoic) Used for Mesozoic basement outcrops in map area; most commonly phaneritic granite to granodiorite that consist of subhedral alkali feldspar (~30–40%), plagioclase (~10%), anhedral interstitial quartz (~25–30%), biotite (~20–25%), and hornblende (≤5%). Some outcrops may correlate to Jqd in the Terrill Mountains (Carlson, in press). May include some metavolcanic and/or metasedimentary rocks not observed in map area. Thickness is at least 400 m.

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