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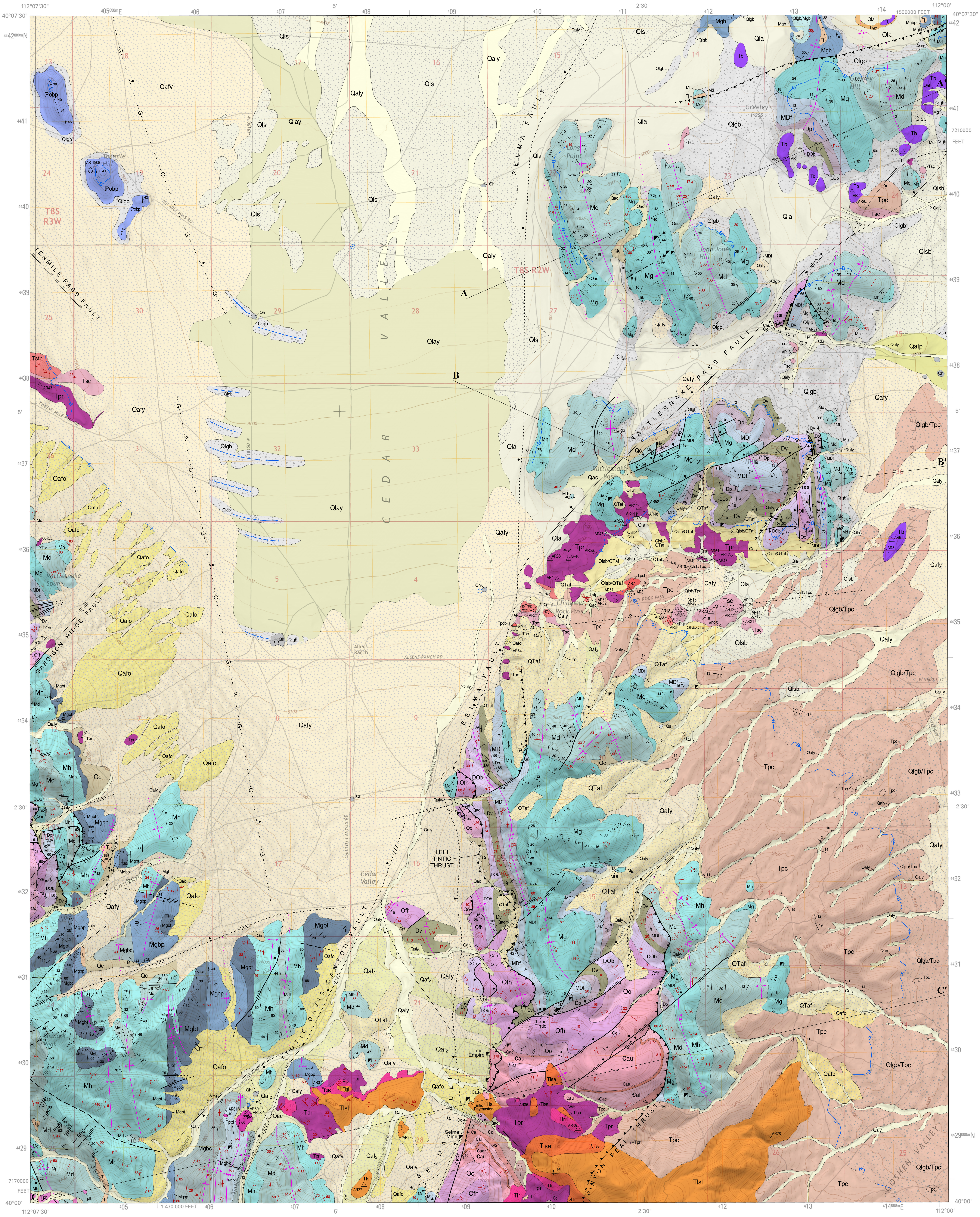

SCALE 1:24,000

1 0.5 0 1 MILE

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CONTOUR INTERVAL 20 FEET

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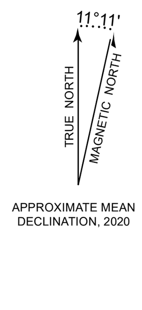

APPROXIMATE MEAN DECLINATION, 2020

GEOLOGIC MAP OF THE ALLENS RANCH QUADRANGLE, UTAH COUNTY, UTAH

by

Adam P. McKean[1], Bart J. Kowallis[2], Eric H. Christiansen[3], Richard W. Bradshaw[4], and Ryan L. Harbor[5]

2020

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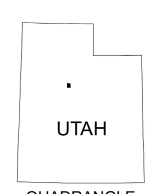

QUADRANGLE LOCATION

Base from USGS US Topo Allens Ranch 7.5' Quadrangle (2017). Projection and datum for base map and GIS data are UTM NAD83. To conform to adjoining geologic maps, the geology is mapped to the 7.5' boundary of older UTM NAD27 base maps to the west and newer UTM NAD83 base maps to the east. The geology is accurately shown relative to cultural and topographic features on the US Topo base map.

Project Manager: Donald L. Clark
Geologic Mapping: 2008-2009, 2018
GIS and Cartography: Adam P. McKean and Lori Steadman

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https://doi.org/10.34191/M-287DM

This map was created from geographic information system (GIS) data.

1	2	3
4		5
6	7	8

1. Fivemile Pass
2. Goshen Pass
3. Soldiers Pass
4. Boulter Peak
5. Goshen Valley North
6. Tintic Junction
7. Eureka
8. Goshen

ADJOINING 7.5' QUADRANGLE NAMES

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GEOLOGIC UNITS

(see booklet for complete unit descriptions)

Qaly	Young stream deposits, undivided
Qaf_1	Level-1 alluvial-fan deposits
Qaf_2	Level-2 alluvial-fan deposits
Qafy	Younger alluvial-fan deposits, undivided
Qafp	Alluvial-fan deposits, related to Provo shoreline and regressive phase of Lake Bonneville
Qafb	Alluvial-fan deposits, related to Bonneville shoreline and transgressive phase of Lake Bonneville
Qafo	Older alluvial-fan deposits, pre-Lake Bonneville
Qc	Colluvial deposits
Qh	Fill and disturbed land
Qls	Lacustrine sand and silt related to Lake Bonneville and Cedar Valley Lake
Qlsp	Lacustrine sand and silt related to the Provo shoreline and regressive phase of Lake Bonneville
Qlgb	Lacustrine gravel and sand related to the Bonneville shoreline and transgressive phase of Lake Bonneville
Qlsb	Lacustrine sand and silt related to the Bonneville shoreline and transgressive phase of Lake Bonneville
Qs	Spring deposits
Qac	Alluvial and colluvial deposits, undivided
Qlay	Lacustrine and younger alluvial-fan deposits, undivided
Qla	Lacustrine and alluvial deposits, undivided
Qlsb/QTaf	Lacustrine sand and silt deposits related to the Bonneville shoreline and transgressive phase of Lake Bonneville over older alluvial-fan deposits
Qlgb/Tpc	Lacustrine gravel and sand related to the Bonneville shoreline and transgressive phase of Lake Bonneville over Pinyon Creek Conglomerate
Qlsb/Tpc	Lacustrine sand and silt deposits related to the Bonneville shoreline and transgressive phase of Lake Bonneville over Pinyon Creek Conglomerate
Qlgb/Mgb	Lacustrine gravel and sand related to the Bonneville shoreline and transgressive phase of Lake Bonneville over Great Blue Limestone, undifferentiated
QTaf	Oldest alluvial-fan deposits
Tj	Jasperoid
Tb	Mosida Basalt
Tpc	Pinyon Creek Conglomerate
Tpcb	Pinyon Creek Conglomerate, breccia member
Tlsl	Laguna Springs Volcanic Group, lava unit
Tlsa	Laguna Springs Volcanic Group, tuff unit
Tsw	Soldiers Pass Formation, White Knolls Member
Tstp	Soldiers Pass Formation, tuff of Twelvemile Pass member
Tsc	Soldiers Pass Formation, Chimney Rock Pass Tuff Member
Tlr	Latite Ridge Latite
Tpr	Packard Quartz Latite, tuff of Rattlesnake Pass member
Tptd	Packard Quartz Latite, tuff of Tintic Davis Canyon member
Tplt	Packard Quartz Latite, lava flow and tuff member
IPobp	Oquirrh Group, Butterfield Peaks Formation
Mgb	Manning Canyon Formation
Mgb	Great Blue Limestone, undivided
Mgbk	Great Blue Limestone, Poker Knoll Limestone Member
Mgbc	Great Blue Limestone, Chiulos Member
Mgbp	Great Blue Limestone, Paymaster Member
Mgbt	Great Blue Limestone, Topliff Limestone Member
Mh	Humbug Formation
Md	Deseret Limestone
Mg	Gardison Limestone
Mg?	Gardison Limestone?
MDf	Fitchville Formation
Dp	Pinyon Peak Limestone
Dv	Victoria Formation
DOb	Bluebell Dolomite
Ofh	Fish Haven Dolomite
Oo	Opohonga Limestone
€a	Ajax Dolomite, undivided
€au	Ajax Dolomite, upper member
€ae	Ajax Dolomite, Emerald Member
€al	Ajax Dolomite, lower member
€o	Opex Formation
€c	Cole Canyon Dolomite

GEOLOGIC SYMBOLS

Contact – Dashed where approximately located; dotted where inferred on cross section

Fault – Sense of offset not known or complex; dashed where approximately located, dotted where concealed; queried where uncertain

Normal fault – Dashed where approximately located, dotted where concealed; bar and ball on downthrown side; arrows on cross section indicate direction of relative movement

Normal fault, geophysical – Inferred from gravity data; dotted where concealed and very approximately located; bar and ball on downthrown side; queried where uncertain

Thrust fault – Dotted where concealed; sawteeth on upper plate; ball and bar on downthrown side indicates later normal offset; arrows on cross section indicate direction of relative movement

Right-lateral strike-slip fault – Dashed where approximately located, dotted where concealed; arrows indicate direction of relative movement; ball and bar on downthrown side indicates later normal offset or oblique-slip; ⊙(toward) ⊕(away) symbols show relative direction of displacement on cross sections

Left-lateral strike-slip fault – Dashed where approximately located, dotted where concealed; arrows indicate direction of relative movement; ball and bar on downthrown side indicates later normal offset or oblique-slip; ⊙ (toward) ⊕(away) symbols show relative direction of displacement on cross sections

Attenuation fault – Dotted where concealed; square teeth on upper plate

Lacustrine shorelines – Major shorelines of Lake Bonneville; mapped at the top of wave-cut bench for erosional shorelines and at the top of constructional bars and barrier beaches; may coincide with geologic contacts

B — Bonneville shoreline (highstand) – Dashed where approximately located

t — Transgressive shorelines (present above the Provo shoreline and below the Bonneville shoreline) – Dashed where approximately located

Crest of lacustrine barrier bar related to Lake Bonneville

A——A' Line of cross section

Hinge zone trace of anticline – Dashed where approximately located; dotted where concealed

Hinge zone trace of syncline – Dashed where approximately located; dotted where concealed

Hinge zone trace of overturned anticline – Dotted where concealed

Hinge zone trace of overturned syncline – Dotted where concealed

Structural measurements – red symbols and dips are from Proctor (1985a, 1985b)

65 65 Strike and dip of inclined bedding

85 85 Strike and dip of overturned bedding

Vertical bedding

25 25 Strike and dip of foliation

Spring

Water well (selected)

Prospect

Adit

Shaft

Sand and gravel pit

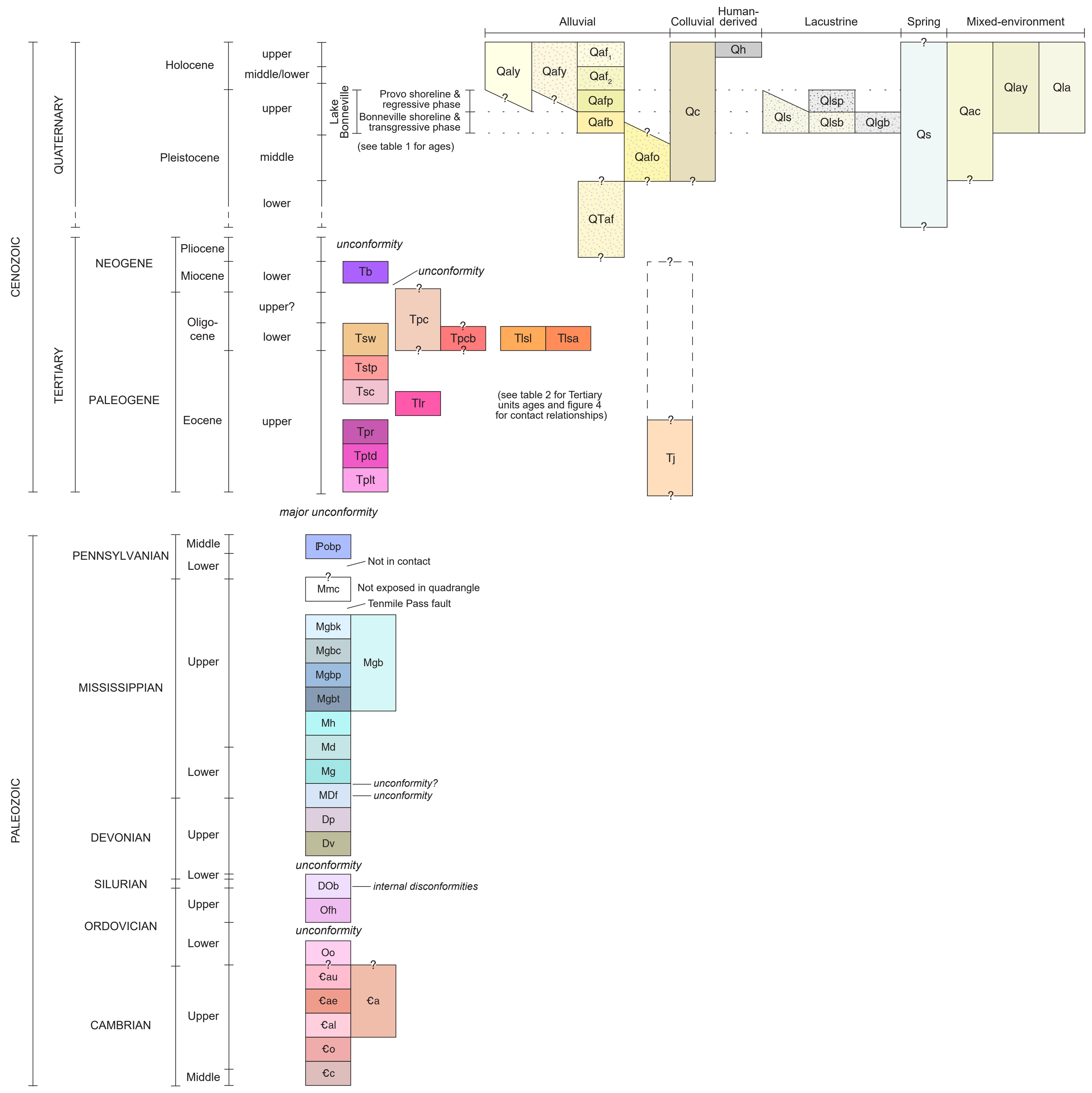
AR6 Rock sample location and number, see table 4 and McKean and others (2013) for geochemical data

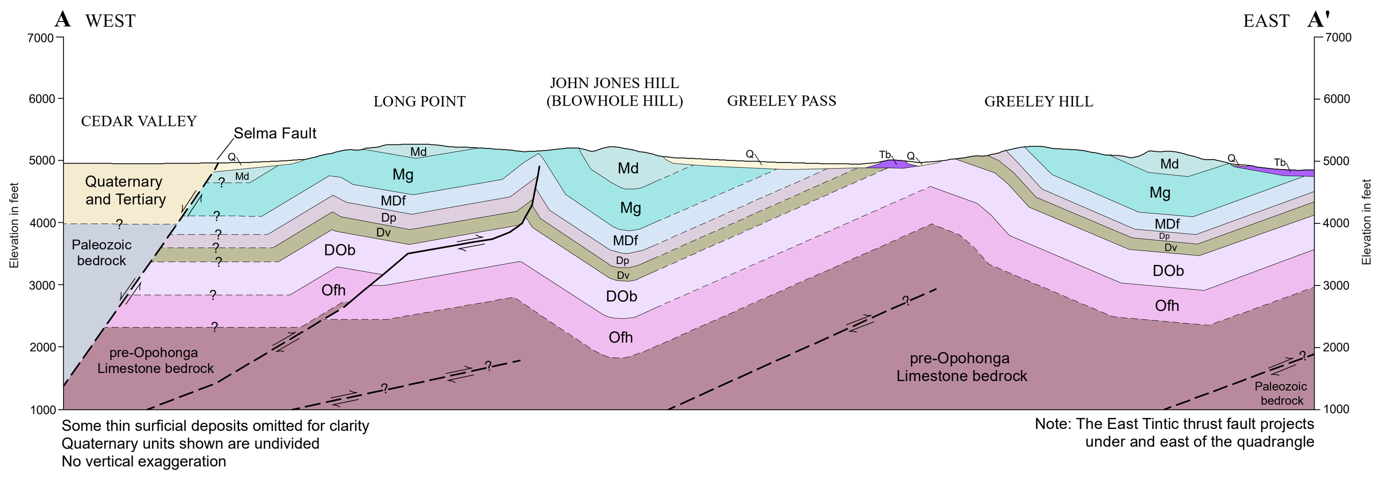
AR-1908 Fossil sample location and number, see unit description for age

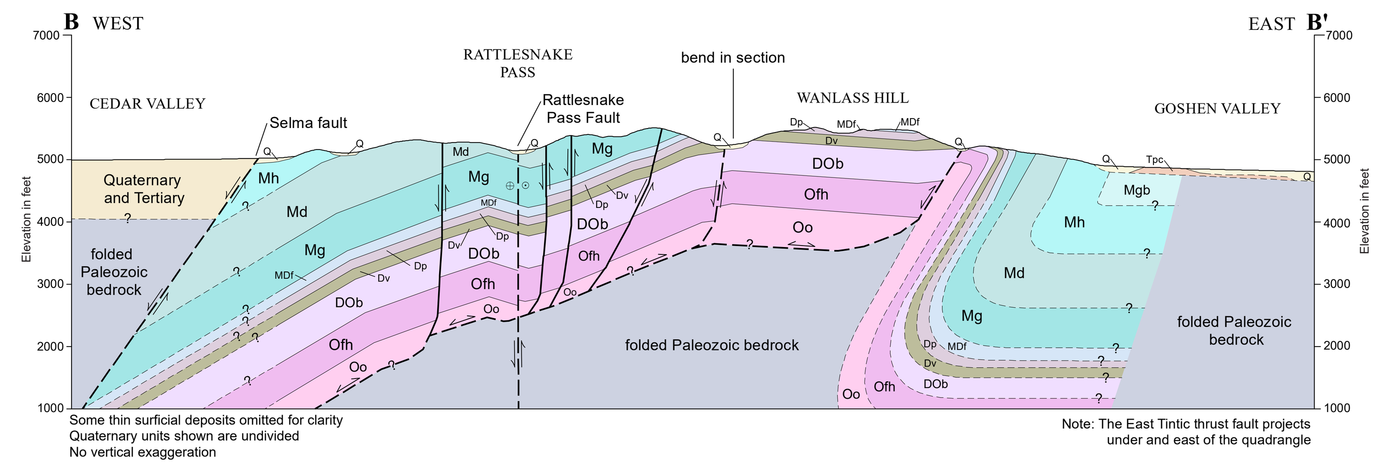
AR-2 Palynology sample location and number, see unit description for age and Chidsey (2016, appendix O)

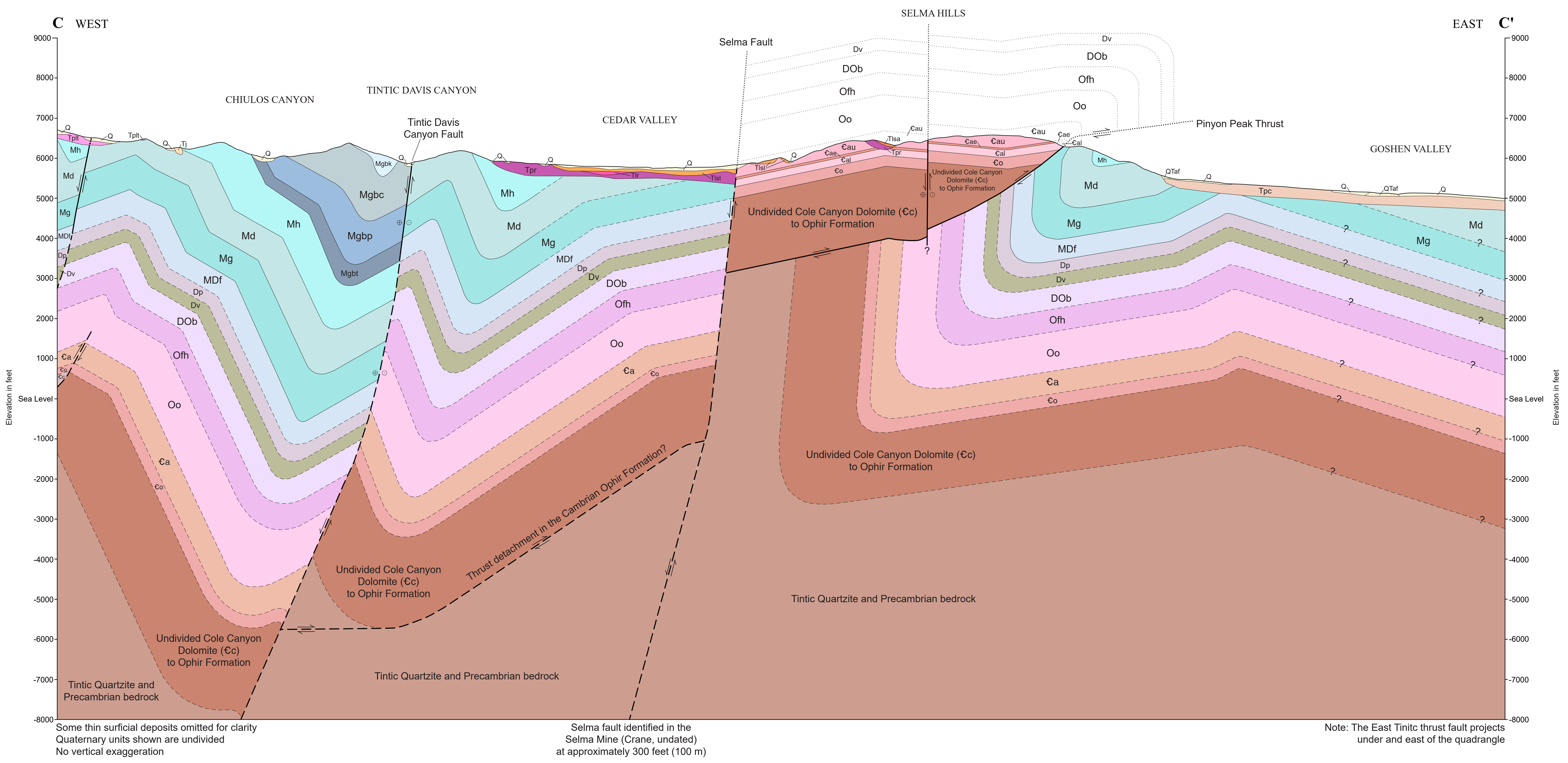
Qlgb/Tpc Stacked unit – Denotes thin cover of first unit overlying second unit

CORRELATION OF GEOLOGIC UNITS









LITHOLOGIC COLUMN

AGE				GROUP/FORMATION/MEMBER		MAP UNIT SYMBOL	THICKNESS Feet (Meters)	LITHOLOGY/NOTES
CENOZOIC	TERTIARY	NEO.	MIO.	Mosida Basalt		Tb	0–40 (0–12)	19.7 Ma Ar/Ar; Unconformity
		PALEOGENE	OLIGOCENE	Soldiers Pass Formation	White Knoll Member	Tsw	20+ (6+)	
					breccia member	Tpcb	30 (10)	
					Pinyon Creek Conglomerate	Tpc	150+ (50+)	
				Laguna Springs Volcanic Group	lava unit	Tlsl	<650 (<200)	32.6 Ma Ar/Ar
					tuff unit	Tlsa	<300 (<100)	33.3 Ma Ar/Ar
			EOCENE	Soldiers Pass Formation	tuff of Twelvemile Pass member	Tstp	15–50 (5–15)	34.6 Ma Ar/Ar
					Chimney Rock Pass Tuff Member	Tsc	10–80 (3–25)	34.6 Ma Ar/Ar
				Latite Ridge Latite		Tlr	0–65 (0–20)	34.6 Ma Ar/Ar
				Packard Quartz Latite	tuff of Rattlesnake Pass mbr	Tpr	0–330 (0–100)	35.0 Ma Ar/Ar
					tuff of Tintic Davis Canyon mbr	Tptd	0–65 (0–20)	35.2 Ma Ar/Ar
					lava flow and tuff member	Tplt	0–30 (0–10)	Major Unconformity
Not in contact								
PALEOZOIC	PENNSYL-VANIAN	MIDDLE		Oquirrh Group	Butterfield Peaks Formation	IPobp	330+ (100+)	Top not exposed in quadrangle; Fusulina; billiard ball limestone (chert); Fusulinella; Base not exposed in quadrangle
		LOWER		Not in contact				
				Manning Canyon Formation		Mmc	-	Not exposed in quadrangle, likely subsurface zone of detachment Tenmile Pass fault
		?		Not in contact				
	MISSISSIPPIAN	UPPER		Great Blue Formation	Poker Knoll Ls Mbr	Mgbk (Mgb)	590–705 (180–215)	Top not exposed in quadrangle
					Chiulos Member	Mgbc (Mgb)	820–950 (250–290)	
					Paymaster Member	Mgbp (Mgb)	590–660 (180–200)	brown chert; *Ekvasophyllum*
					Topliff Limestone Member	Mgbt (Mgb)	295–330 (90–100)	*Endothyra*
				Humbug Formation		Mh	690–750 (210–230)	
		LOWER		Deseret Limestone	Uncle Joe Member	Md	660–820 (200–250)	*Rhipidomella*
					Tetro Member			cherty ls
					Delle Member			phosphatic shale
				Gardison Limestone		Mg	500–660 (150–200)	straparollid gastropods; Unconformity?
				Fitchville Formation		MDf	330–500 (100–150)	laminated stromatolitic ls; Unconformity
	DEVONIAN	UPPER		Pinyon Peak Limestone		Dp	100–330 (30–100)	
				Victoria Formation		Dv	300 (90)	
		LOWER		Bluebell Dolomite		DOb	330–500 (100–150)	Unconformity (Stansbury uplift); *Virgiana*; Internal disconformities; *Streptelasma*
	SILURIAN							
	ORDOVICIAN	UPPER		Fish Haven Dolomite		Ofh	330–500 (100–150)	Unconformity (Tooele arch)
		LOWER		Opohonga Limestone		Oo	500–1000 (150–300)	*Pseudocybele*; intraformational cg; *Symphysurina*
		?						
	CAMBRIAN	UPPER		Ajax Dolomite	Upper Member	€au (€a)	300–330 (90–100)	
					Emerald Member	€ae (€a)	30 (10)	
					Lower Member	€al (€a)	130–160 (40–50)	*Eoorthis*
				Opex Formation		€o	260–300 (80–90)	*Elvinia zone*
				Cole Canyon Dolomite		€c	330+ (100+)	*Eldoradia*
		MIDDLE						Base not exposed in quadrangle

Lithologic column modified from Hintze and Kowallis, 2009
Not to scale

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MAP 287DM
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2020

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***Cover photo:** View to the northwest in the Chimney Rock Pass area of light-gray tuff of Rattlesnake Pass member of the Packard Quartz Latite (late Eocene). The hills on either side of the tuff contain outcrops of the Mississippian Gardison Limestone. The Packard Quartz Latite and other younger volcanic rocks are deposited within east-west trending paleovalleys that incised into the East Tintic thrust sheets. Snow-capped southern Oquirrh Mountains in the background.*

Suggested citation:

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GEOLOGIC MAP OF THE ALLENS RANCH QUADRANGLE, UTAH COUNTY, UTAH

by Adam P. McKean, Bart J. Kowallis, Eric H. Christiansen, Richard W. Bradshaw, and Ryan L. Harbor

INTRODUCTION

The Allens Ranch 7.5' quadrangle is located in the southern end of Cedar Valley and west side of Goshen Valley, Utah County, Utah. The quadrangle includes the northern part of the East Tintic Mountains (figures 1 and 2). The valleys occupy about one quarter of the quadrangle and represent the infilled extensional basin between Gardison Ridge and the Selma Hills (figure 2). The Allens Ranch quadrangle is within the North Tintic mining district; which is north of the Main Tintic and East Tintic mining districts, all three are subdivisions of the greater Tintic mining district. The greater Tintic mining district, related to Cenozoic magmatism, is an important Au-Ag-Cu-Pb-Zn district that produced collectively over $10.5 billion worth of gross metal (Krahulec, 2018, using data through 2017 and modern metal prices). Most of the valley is pasture and farmland. The quadrangle is also a popular outdoor recreation, off-roading, and shooting area, especially near Chimney Rock Pass.

This geologic map was completed as part of McKean's M.S. thesis work at Brigham Young University (BYU) conducted between 2008 and 2010 (McKean, 2011), with research focused on two main topics. The first was remapping and correlating Eocene to Miocene volcanic stratigraphy with the nearby Soldiers Pass and East Tintic volcanic fields to provide a better foundation for understanding and interpreting the magmatic and overall geologic history of the region. The middle Cenozoic magmatism was an important factor in Au-Ag-Cu-Pb-Zn mineralization in the East Tintic mining district, providing heat, fluids, sulfur, and metals for the ore-forming systems (Morris and Lovering, 1979). The second research topic was investigating the origin of northeast-trending faults in the area (see McKean and others, 2011). To the south in the East Tintic mining district, larger and richer replacement ore bodies are localized where thrust faults are cut by northeast-trending fissures and tear faults (Morris and Lovering, 1979). Study of these faults in the central part of the mining district is hampered by extensive volcanic cover, but the faults are well exposed in the Allens Ranch quadrangle. Consequently, we were able to study field relationships, construct maps, and collect data for various kinematic indicators to better constrain the orientation of the stress field during formation of the structures and also to better understand the relationships between faulting and mineralization. Understanding the structural history of the faults is important in determining the timing and nature of the mineralization; thrust-related faults from the Sevier orogeny could serve as mineralization hosts, whereas purely Basin and Range extension-related faults do not. The combined volcanic stratigraphy and fault analyses of exposed units and structures in the quadrangle may be used as analogs for understating the timing and nature of mineralization of ore-bearing structures to the south in the East Tintic mining district that are covered by a thick Paleogene volcanic field. While some of the research completed for that study is included here, see also McKean (2011) and McKean and others (2011) for more detailed information.

GEOLOGY

Within the Allens Ranch quadrangle, Paleozoic bedrock is mostly Cambrian to Pennsylvanian passive margin marine deposits. The Paleozoic rocks were deformed by the Sevier orogeny into tight folds with associated thrust faults. Folds typically have straight limbs and tight fold hinges (see cross sections on plate 2) and in some areas fold limbs are overturned. An erosional unconformity separates the Paleozoic sedimentary rocks from Paleogene volcanic rocks. The volcanic rocks were deposited in east-west paleovalleys incised into the East Tintic area thrust belt. Erosional remnants of Neogene extension-related basalts drape the low hills in and to the north of the quadrangle. Both the thrust faults and volcanic rocks have been affected by later normal faulting during Basin and Range extension. Lacustrine deposits from late Pleistocene Lake Bonneville cover much of the valley below approximately 5180 feet (1579 m) elevation. The next two sections, "Bedrock Stratigraphy and Geologic Structure" and "Surficial Geology," summarize the geologic history of the quadrangle.

Bedrock Stratigraphy and Geologic Structure

During the Paleo- to Mesoproterozoic, various terranes were accreted to the North American Archean craton creating the basement rock for this region (Nelson and others, 2002; Dickinson, 2006; Whitmeyer and Karlstrom, 2007). The closest exposures of these basement rocks are in the Wasatch Range east of Santaquin (Nelson and others, 2002) about 19 miles (30 km) northeast of the quadrangle. In the Neoproterozoic, a period of rifting broke up the supercontinent Rodinia creating basins into which thick sequences of clastic sediment were de-

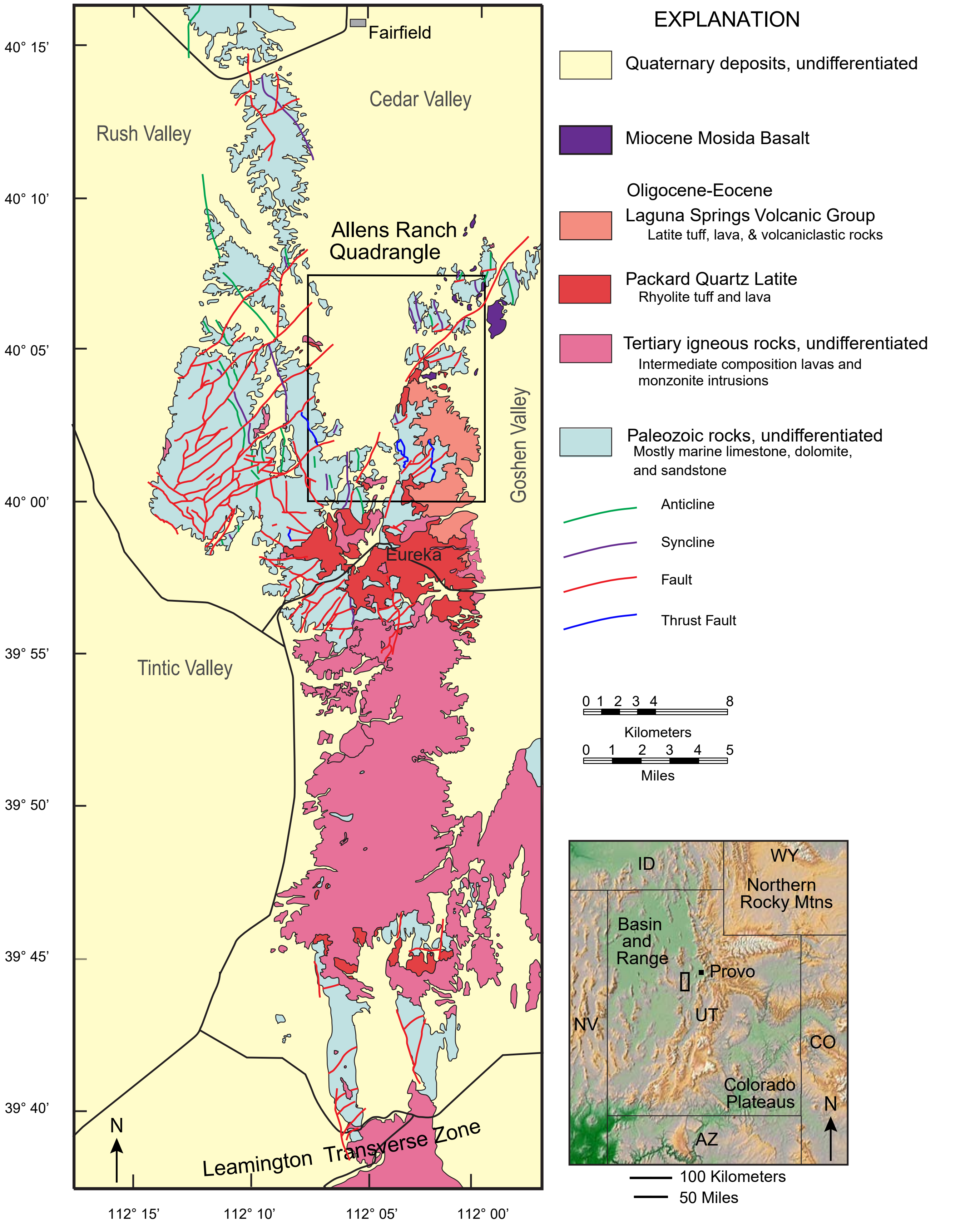

***Figure 1.** Simplified geologic map of the East Tintic Mountains and some adjacent areas showing the location of the Allens Ranch quadrangle, modified from Morris and Lovering (1961, plate 2). Rectangle on smaller shaded relief map shows the location of this geologic map. Major Quaternary faults not shown, intent is to show bedrock structure. Sevier orogeny fault and fold lines in bedrock and Quaternary deposits are simplified as solid lines and do not indicate Quaternary movement of those structures.*

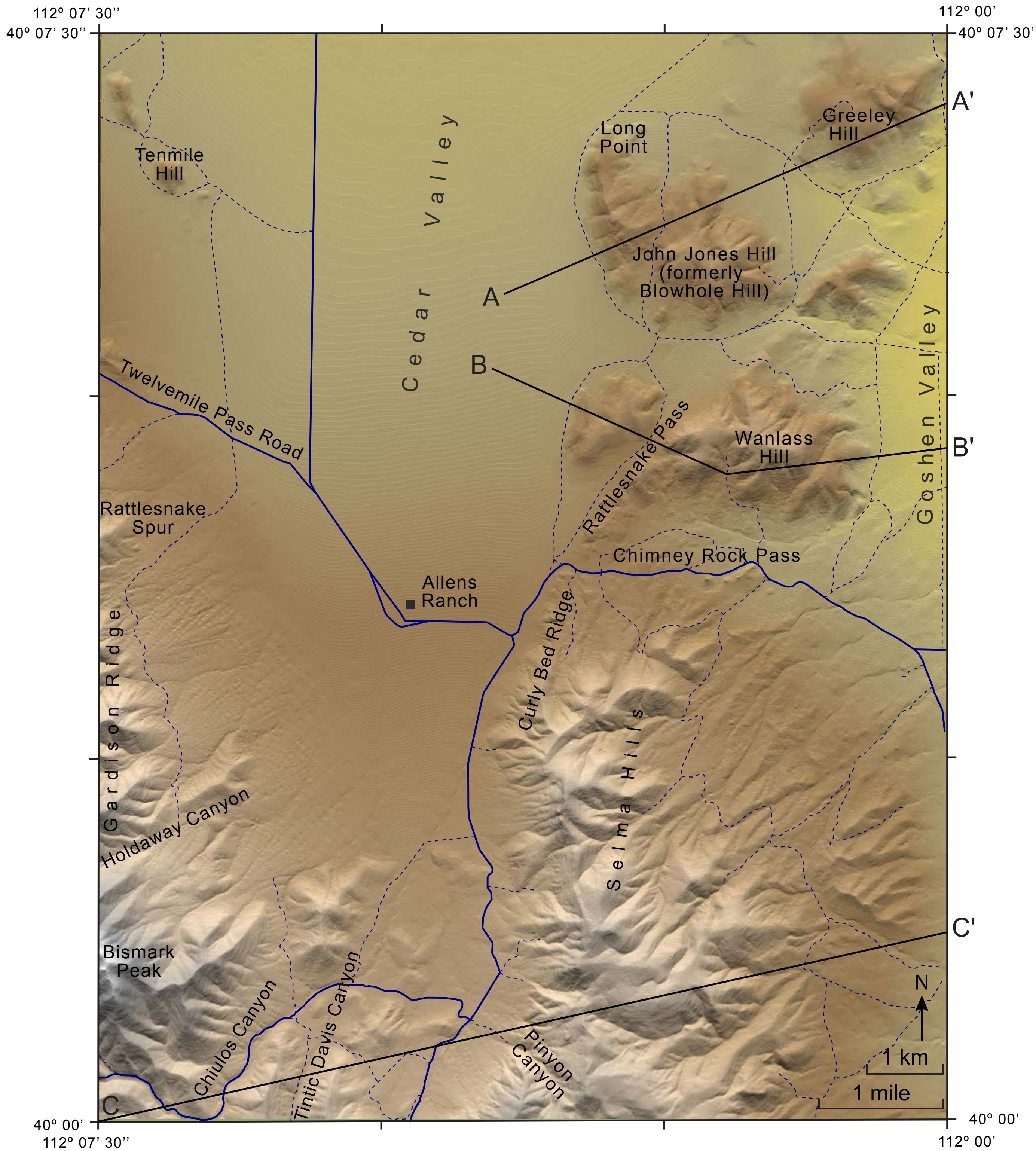

***Figure 2.** Shaded relief map of the Allens Ranch quadrangle showing major geographic features and access roads. Some informal geographic names are shown. Solid blue lines are graded unpaved roads and dashed lines are ungraded dirt roads and tracks. Thick solid black lines are the locations of cross sections A-A', B-B', and C-C' (see plate 2). Pinyon Peak is located just south of Pinyon Canyon in the Eureka quadrangle.*

posited (Yonkee and others, 2014). Neoproterozoic Big Cottonwood Formation bedrock is exposed in the Tintic Junction quadrangle to the southwest (Morris, 1964b).

Separated from the Neoproterozoic by an erosional unconformity, Paleozoic strata represent a long period of deposition and subsidence along the passive western continental margin of North America. Thick sections of mostly shallow marine sediments accumulated in this setting (Dickinson, 2006; Yonkee and others, 2014). The oldest bedrock units exposed in the quadrangle are marine deposits of Cambrian Cole Canyon Dolomite (₵c), followed by the Opex Formation (₵o) and Ajax Dolomite (₵al, ₵ae, ₵au). The Cambrian deposits are overlain by Ordovician marine deposits of the Opohonga Limestone (Oo). An Ordovician unconformity from the Ordovician Tooele arch (Hintze, 1959) separates the Opohonga from the overlying Fish Haven Dolomite (Ofh) (Morris and Lovering, 1961, and references therein; Ethington and others, 2016). The Fish Haven is overlain by the Ordovician, Silurian, and Devonian Bluebell Dolomite (DOb), which likely contains one (or more) internal disconformities (Morris and Lovering, 1961). Subsidence during this time was interrupted by several tectonic events to the west that shed clastic sediment into the shallow marine environment and produced several unconformities (Morris and Lovering, 1961; Dickinson, 2006). The Stansbury uplift, possibly a Late Devonian manifestation of the Antler orogeny or reactivation of the Uinta structural zone, is one of these smaller orogenies that contributed sands to form the Devonian Victoria Formation (Dv) (Rigby, 1959; Morris and Lovering, 1961; Tooker, 1999). Marine Devonian to Mississippian units are the Pinyon Peak Limestone (Dp), Fitchville Formation (MDf), Gardison Limestone (Mg), Deseret Limestone (Md), Humbug Formation (Mh), and Great Blue Limestone (Mgb). The transition from Mississippian to Pennsylvanian rocks is not exposed in the quadrangle but elsewhere occurred within the Manning Canyon Formation (Mmc) (see Biek and others, 2009; Clark and others, 2012).

Interbedded marine deposits of the Pennsylvanian Butterfield Peaks Formation (ℙobp) of the Oquirrh Group are exposed on the northwestern margin of the quadrangle. The Oquirrh Group was deposited in the Oquirrh basin during the late Paleozoic. This basin was probably created by crustal subsidence associated with a deformational episode of the Ancestral Rocky Mountains and/or the Antler orogeny (Hintze and Kowallis, 2009). During that time about 20,000 feet (~6100 m) of marine strata of the Oquirrh Group were deposited into the basin (Constenius and others, 2011). Only the lower portion of the Butterfield Peaks Formation is exposed in the quadrangle.

Following the Triassic breakup of Pangaea, eastward subduction of oceanic crust and the accretion of terranes began on the western margin of North America during the Late Triassic Cordilleran orogeny (DeCelles, 2004; Yonkee and Weil, 2011, 2015). Deformation proceeded eastward. By the Late Cretaceous, steep- and subsequent flat-slab subduction related to the Sevier orogeny affected central Utah and caused folding and faulting of Paleozoic strata; this subduction created the fold and thrust system of the East Tintic area (figure 3). The East Tintic thrusts are considered internal thrust sheets of the Provo (Charleston-Nebo) salient of the Sevier fold-thrust belt (DeCelles, 2004; Kwon and Mitra, 2004). The East Tintic thrust system deformed Paleozoic units in the area (McKean and others, 2011), including those in the Allens Ranch quadrangle, and the upper plate of the Charleston-Nebo allochthon incorporated older Precambrian basement as well as Paleozoic-Mesozoic strata (DeCelles, 2004). The Sevier orogeny produced an altiplano-type plateau as orogenic processes thickened the continental crust (Best and others, 2009). Erosion of the Sevier orogenic belt produced rugged highlands bordering a foreland basin to the east (Horton and others, 2004; Morris and Lovering, 1979).

Following the Sevier orogenic period of rapid flat-slab subduction, the subducting slab beneath western North America began to founder or roll back, producing a flare-up of subduction-related volcanic activity (Best and Christiansen, 1991; Christiansen and others, 2007). During this time, erosional valleys were filled by late Paleogene volcanic and sedimentary rocks (figure 4) (e.g., Morris and Lovering, 1979; McKean, 2011). The Paleogene volcanic section consists of a suite of high-potassium extrusive rocks. Rhyolite, trachydacite, and trachyte ignimbrites, along with latite lavas and block-and-ash flows dominate the succession (Morris and Lovering, 1979; Moore, 1993; Christiansen and others, 2007; Moore and others, 2007; McKean, 2011). In the Allens Ranch quadrangle, the volcanic units are from the overlapping Soldiers Pass and East Tintic volcanic fields (figure 4). The oldest volcanic unit is rhyolite of the late Eocene Packard Quartz Latite (Tptd, Tpr, Tplt). It is overlain in places by trachytic Latite Ridge Latite (Tlr). The next-oldest unit is the late Eocene to Oligocene Soldiers Pass Formation; a number of the formal and informal members are present in the quadrangle, including the Chimney Rock Pass Tuff Member (Tsc), tuff member of Twelvemile Pass (Tstp), and the sedimentary White Knoll Member (Tsw). The Soldiers Pass Formation is followed by the Oligocene Laguna Springs Volcanic Group (Tlsl, Tlsa). The overlying volcaniclastic Pinyon Creek Conglomerate (Tpc) includes a volcanic breccia member (Tpcb) and likely interfingers with the White Knoll Member of the Soldiers Pass Formation.

After this volcanically active period, tectonics changed, and the region experienced Miocene Basin and Range extension, bimodal volcanism (Best and Christiansen, 1991), and the eruption of the extension-related Mosida Basalt (Tb) (Christiansen and others, 2007). The Selma fault on the southern boundary of the quadrangle, as well as other unnamed concealed faults along the margins of the valleys, are Miocene to Quaternary expressions of continued Basin and Range extensional normal faulting. During this period of extension, locally derived basin fill accumulated in the valley graben. Miocene (older) basin fill (Salt Lake Formation) is not exposed in the

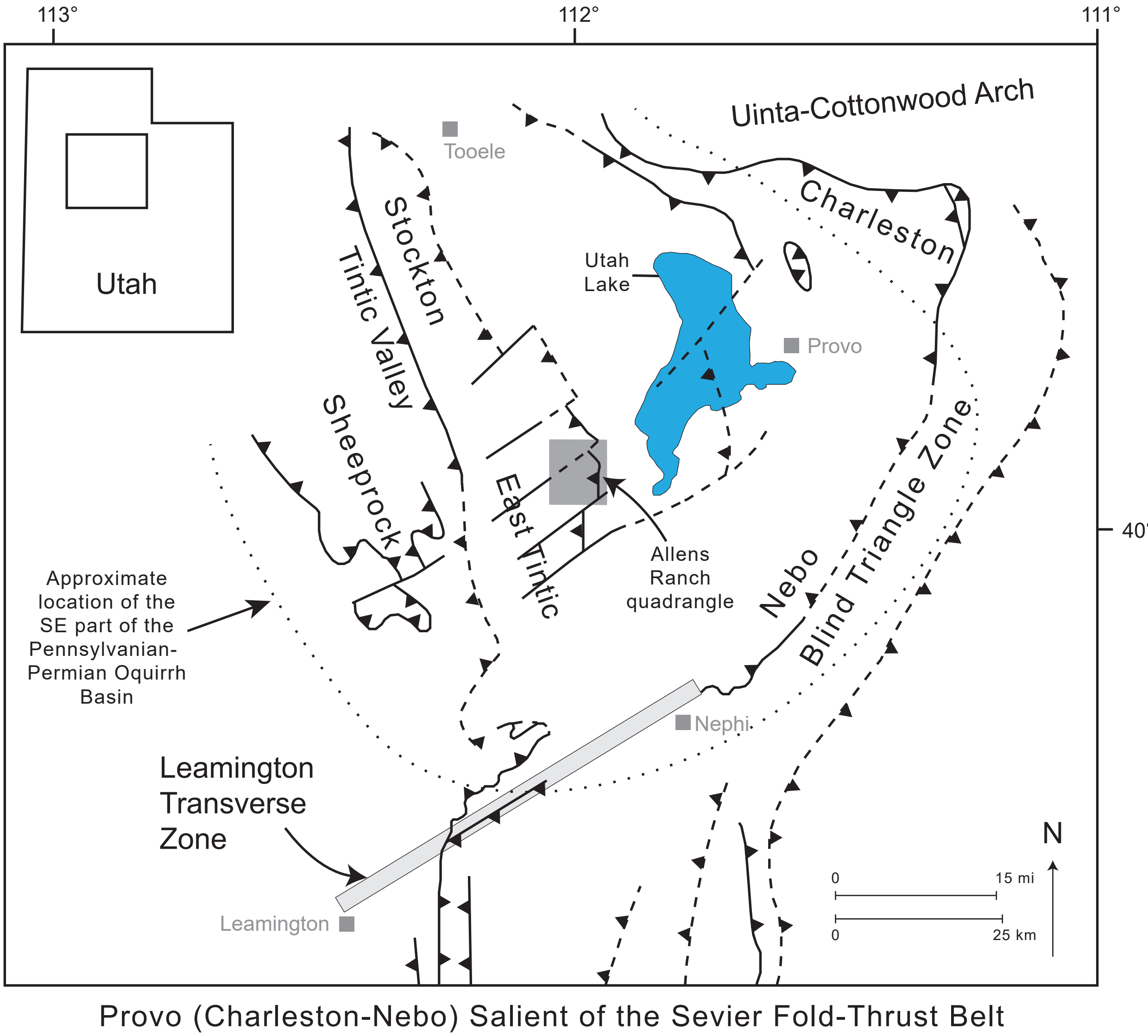

Figure 3. *Location of the Provo (Charleston-Nebo) salient, internal thrust sheets, the Allens Ranch quad¬rangle, and the approximate location of the Pennsylvanian-Permian Oquirrh basin (modified from Kwon and others, 2007; Hintze and Kowallis, 2009).*

quadrangle but crops out in nearby areas of the Rush Valley and Lynndyl 30' x 60' quadrangles (Pampeyan, 1989; Clark and others, 2012). The most recent surface fault ruptures in the quadrangle are likely older than the latest Pleistocene, as no Lake Bonneville or Holocene deposits are offset.

Surficial Geology

Surficial geologic units within the quadrangle consist of unconsolidated lacustrine, alluvial, colluvial, and spring deposits of mostly late Pleistocene and Holocene age. Late Pleistocene Lake Bonneville covered much of northwestern Utah and adjacent parts of Idaho and Nevada between 30,000 and 13,000 years ago (all ages in this section are in calibrated years before present), and can be divided into transgressive, overflowing, and regressive phases (Oviatt and others, 1992; Godsey and others, 2005, 2011; Oviatt, 2015; see table 1). During the Bonneville shoreline highstand water levels reached as high as approximately 5140 to 5180 feet (1567–1579 m) in the quadrangle. Table 1 provides time constraints and elevations for Lake Bonneville geologic features and map units in the quadrangle.

PREVIOUS WORK

The early geology and ore studies of the Tintic area were completed by Lindgren and others (1919). Other related geologic studies in the area include work by several BYU Masters' students (Rigby, 1949; Johns, 1950; Williams, 1951; Hoffman, 1951; Moulton, 1951; Calderwood, 1951; Dearden, 1954; Foster, 1959; Larsen, 1960; Floyd, 1993; Moore, 1993; McKean, 2011; Allen, 2012). Mapping by Rigby (1952), Proctor and others (1956), and Proctor (1985b) provided the basic understanding of the geology of this quadrangle. Unfortunately, Paul Proctor passed away before finalizing his map, which exists only as an open-file report with the Utah Geological

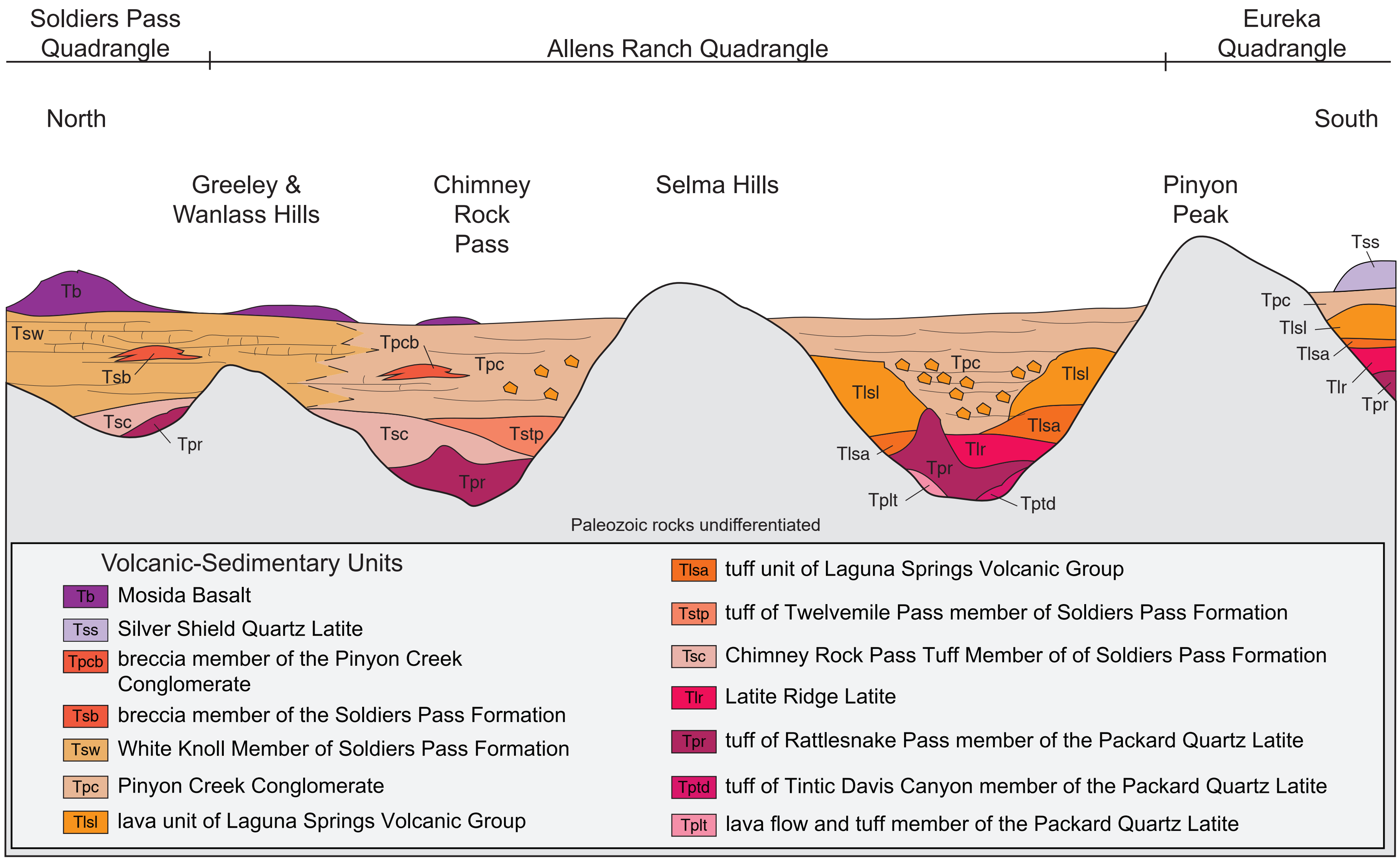

Figure 4. *Idealized north-south schematic diagram across the Allens Ranch quadrangle showing vertically exaggerated east-west paleovalleys in-filled by Tertiary volcanic and sedimentary rocks. Small blocks of* Tlsl *in* Tpc *are intended to represent clasts of* Tlsl *in* Tpc.

Table 1. *Ages of major shoreline occupations of Lake Bonneville with shoreline elevations in the Allens Ranch quadrangle.*

Lake Cycle and Phase	Shoreline (map symbol)	Age		Shoreline Elevation feet (meters)
		radiocarbon years (^{14}C yr B.P.)	calibrated years (cal yr B.P.)[1]	
Lake Bonneville				
Transgressive phase	Stansbury shorelines	22,000–20,000[2]	26,000–24,000	Not present[3]
	Bonneville (B) flood	~15,000[4]	~18,000	5140–5180 (1567–1579)
Overflowing phase	Provo	15,000–12,600[5]	18,000–15,000	Not recognized[6]
Regressive phase	Regressive shorelines	12,600–11,500[5]	15,000–13,000	Not present[3]
Cedar Valley Lake	Cedar Valley	15,000[4,7]	18,000	Not recognized[6]

1 All calibrations made using OxCal 14C calibration and analysis software (version 4.3.2; Bronk Ramsey, 2009; using the IntCal13 calibration curve of Reimer and others, 2013), rounded to the nearest 500 years.

2 Oviatt and others (1990)

3 Stansbury, overflow, and regressive shorelines are provided for reference only, as they are not present in the quadrangle and are downslope of the lowest elevations in the quadrangle.

4 Bonneville shoreline highstand duration may have been shorter than our rounding error of 500 years; age represents lake culmination (Oviatt, 2015; Miller, 2016; and references therein).

5 Godsey and others (2005, 2011), Oviatt (2015), Miller (2016) for the timing of the occupation of the Provo shoreline and subsequent regression of Lake Bonneville to near Great Salt Lake level. Alternatively, data in Godsey and others (2005) may suggest that regression began earlier, shortly after 16.5 cal ka (see sample Beta-153158, with an age of 13,660 ± 50 ^{14}C yr B.P. [16.5 cal ka] from 1.5 m below the Provo shoreline). Also, lacustrine carbonate deposits in caves reported by McGee and others (2012) seem to support an earlier Lake Bonneville regression beginning around 16.4 cal ka.

6 Provo and Cedar Valley Lake shorelines likely present in the quadrangle but not recognized.

7 Estimated age when Lake Bonneville dropped below the Cedar Valley thresholds during the flood, from data in Oviatt (2015 and references therein). Duration of Cedar Valley Lake occupation is unknown.

Survey (UGS) (Proctor, 1985b). We used the preliminary geologic map by Proctor (1985b) as a source for our mapping. Since Proctor's (1985b) mapping of the Allens Ranch quadrangle, the volcanic stratigraphy (figure 4) in the quadrangle was substantially revised and correlated with related volcanic units in adjacent mapped quadrangles (Christiansen and others, 2007; Biek and others, 2009). The volcanic stratigraphy, unit descriptions, and rock geochemistry in the East Tintic and Soldiers Pass volcanic fields have been described in detail in several published studies. The East Tintic volcanic field was described chiefly by Morris and Lovering (1979), Kim (1997, 1999), Moore (1993), and Moore and others (2007), whereas the Soldiers Pass volcanic field was described by Christiansen and others (2007) and mapped by Biek and others (2009). Others have described the chemical analysis, stratigraphy, K-Ar and ^{40}Ar/^{39}Ar dating (table 2) of the volcanic units and geologic history of the region (Laughlin and others, 1969; Hannah and Macbeth, 1990; McKee and others, 1993; UGS and New Mexico Geochronology Research Laboratory [NMGRL], 2007; Hannah, J.L., and Snee, L., unpublished data [D.L. Clark, UGS, written communication, 2010]). Mapping was also conducted in the quadrangle by BYU Geology Field Camp students in 2007, 2008, and 2009; the students' mapping was referenced when creating this geologic map in addition to our own fieldwork. The geology of the surrounding 7.5' quadrangles share common structure, volcanic rocks, and Paleozoic stratigraphy with the Allens Ranch quadrangle (figure 5). Additional studies of the East Tintic Mountain area volcanic rocks, structure, stratigraphy, and mines were published by Proctor and Clark (1956), Proctor (1964, 1985a), Morris and Lovering (1961, 1979), Morris (1964a, 1964b), Morris and Shepard (1964), Keith and others (2009), and Ethington and others (2016). Their work provides valuable information on the Tertiary volcanic rocks, Paleozoic rocks, and structures of the East Tintic Mountains.

A variety of structural studies involving many different techniques and hypotheses have been published on the Provo (Charleston-Nebo) salient, the orocline of which the East Tintic thrust system is a part (Paulsen and Marshak, 1998). Rigby (1952), in one of the early studies of the area, addressed some of the basic structural components, including thrust and normal faults of what he informally called the Selma Hills (figure 2). Similarly, Proctor's (1985b) mapping identified most of the faults within the quadrangle, but his detailed map is missing sense-of-shear indicators for the faults and kinematic data, especially for the NE-trending faults. Kwon and Mitra (2004) studied the strain distribution, history, and kinematics of the Provo salient and included the East Tintic thrusts in a large-scale orocline development model. McKean and others (2011) showed that the Sevier-age folds and thrust sheets, including the high-angle northeast-trending faults, formed with a maximum paleostress and transport direction of 82°. Some of the northeast-trending Sevier-age faults in the area also show evidence of reactivation as normal faults during Basin and Range extension.

METHODS

Mapping of surficial deposits by the UGS is based on age and depositional environment or origin. The letters of the map units in order indicate (1) age (geologic period, e.g., Q for

Table 2. *Summary of $^{40}Ar/^{39}Ar$ and K-Ar ages of volcanic units from the East Tintic and Soldiers Pass volcanic fields, central Utah.*

Formation	Mosida Basalt					Laguna Springs Volcanic Group					
Member						lava unit	Tintic Delmar Latite		Pinyon Queen Latite		
Sample#	AR-608	SOLDPASS-2	SP-3303	SP-4003	74-KA-1	AR-1608			TAD-11-67		ET134
Latitude (°N)	40.10797	40.167	40.17759	40.15062	40.1541	40.00682	40.0103*		39.9969		39.9936
Longitude (°W)	112.02154	111.983	111.97360	111.98955	112.0097	112.02439	112.0241*		112.0361		112.0438
Material	whole rock					sanidine	biotite	hornblende		biotite	hornblende
Method	$^{40}Ar/^{39}Ar$	K-Ar	$^{40}Ar/^{39}Ar$	$^{40}Ar/^{39}Ar$	K-Ar	$^{40}Ar/^{39}Ar$	K-Ar	K-Ar	K-Ar	$^{40}Ar/^{39}Ar$	$^{40}Ar/^{39}Ar$
Age (Ma)	19.74	17	19.47	19.65	21.4	32.66	32.2	32.3	27.8	33.34	33.29
Error ±	0.05	0.5	0.14	0.17	2.5	0.03	1	1	0.8	0.15	0.09
Reference^	8	4	5	5	3	8	2	2	1	6	6

Formation	Soldiers Pass Formation							Latite Ridge Latite	
Member	breccia member	Chimney Rock Pass Tuff Member					tuff of Twelvemile Pass mbr		
Sample#	SP-3205	AR-1108	SP-603A	SP-1603B	AR-105	SP-192	AR-2606	TM-4	?
Latitude (°N)	40.15045	40.06179	40.20338	40.15518	40.06028	40.20418	40.06342	39.7969	?
Longitude (°W)	111.99398	112.03631	111.97778	111.97959	112.02833	111.97775	112.04957	112.0297	?
Material	groundmass	sanidine				sanidine	plagioclase	biotite	
Method	$^{40}Ar/^{39}Ar$	$^{40}Ar/^{39}Ar$	$^{40}Ar/^{39}Ar$	$^{40}Ar/^{39}Ar$	$^{40}Ar/^{39}Ar$	$^{40}Ar/^{39}Ar$	$^{40}Ar/^{39}Ar$	$^{40}Ar/^{39}Ar$	$^{40}Ar/^{39}Ar$
Age (Ma)	33.73	34.61	34.7	34.7	34.73	34.18	34.62	34.64	35.1
Error ±	0.65	0.02	0.07	0.07	0.08	0.24	0.16	0.17	0.2
Reference^	5	8	5	5	5	6	8	7	9

Formation	Packard Quartz Latite					
Member	tuff of Rattlesnake Pass mbr					tuff of Tintic Davis Canyon mbr
Sample#	AR-908	?	?	TAD-6-67		AR-1708
Latitude (°N)	40.10956	?	?	39.9777		40.00961
Longitude (°W)	112.00526	?	?	112.0650		112.09603
Material	sanidine			biotite	sanidine	sanidine
Method	$^{40}Ar/^{39}Ar$	$^{40}Ar/^{39}Ar$	$^{40}Ar/^{39}Ar$	K-Ar	K-Ar	$^{40}Ar/^{39}Ar$
Age (Ma)	35.08	34.8	34.7	32.8	32.7	35.21
Error ±	0.03	0.1	0.1	1	1	0.03
Reference^	8	9	9	1	1	8

Note: Location data are based on NAD83.
* indicates sample location estimated from cadastral system location provided by the reference

References^
[1]Laughlin and others, 1969
[2]Morris and Lovering, 1979
[3]Moore and McKee, 1983
[4]McKee and others, 1993
[5]Christiansen and others, 2007
[6]Moore and others, 2007
[7]UGS and NMGRL, 2007
[8]McKean, 2011; Christiansen and others, 2013
[9]Hannah, J.L., and Snee, L., (written communication, D.L. Clark, 2010)

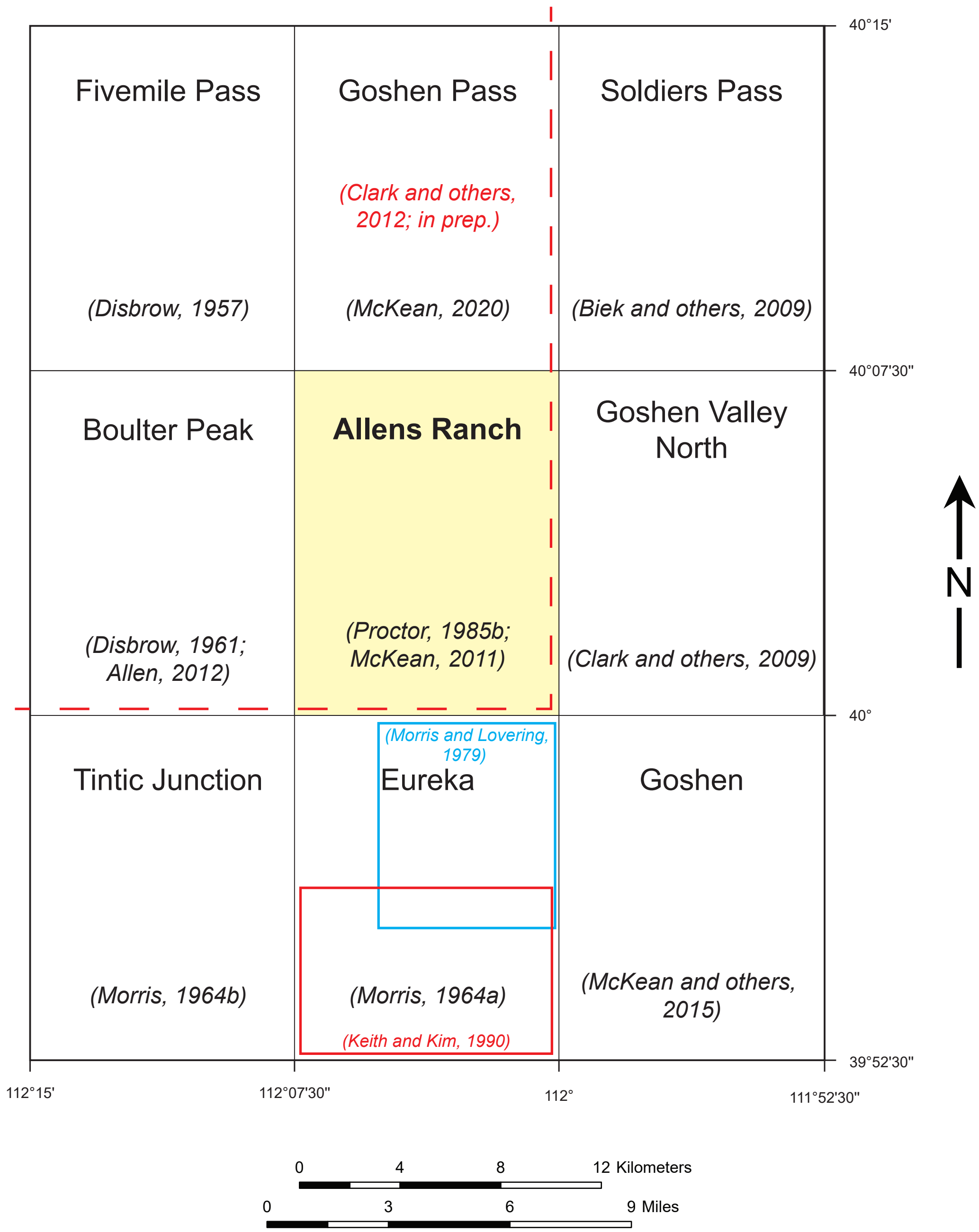

Figure 5. *Index map showing selected geologic maps available for the Allens Ranch and surrounding 7.5' quadrangles.*

Quaternary); (2) primary depositional environment or origin, usually determined from geologic setting, landform or morphology; (3) grain size(s), bedding, or other distinctive characteristics of the deposits; and (4) additional significant information, such as tighter age constraints (Doelling and Willis, 1995). In the Bonneville basin ages are related to the phases of Lake Bonneville or numbered, whereby 1 is the youngest (active) deposit. For example, unit Qal_1 is a Quaternary (Q) surficial deposit of alluvial stream origin (al), and the number one indicates it is young and potentially historically active.

Mapping for the project was done using stereographic pairs of aerial photographs, including black-and-white aerial photographs at a scale of 1:20,000 from the U.S. Department of the Interior Bureau of Reclamation (1939) and natural color aerial photographs at approximately 1:24,000 scale from IntraSearch (1980). Some contacts were revised using Google 2017 archive orthophotographs (Utah Automated Geographic Reference Center [AGRC], 2017) and 0.5-meter lidar (AGRC, 2018). The geologic map was made by transferring the geology from the aerial photographs to a GIS database using the programs ArcGIS, VR1, and VR2 for a target scale of 1:24,000, using 1980 IntraSearch photographs. Some additional mining prospects, adits, and shafts added to the geologic mapping were modified from field mapping from locations and data in the UGS Utah Mineral Occurrence System (UGS, undated).

MAP UNIT DESCRIPTIONS

QUATERNARY

Alluvial Deposits

Qaly **Young stream deposits, undivided** (Holocene to upper Pleistocene?) – Poorly to moderately sorted pebble to cobble gravel, with boulders near bedrock sources, with a matrix of sand, silt, and clay; subangular to rounded clasts; thin to medium bedded with planar bedding and cross-bedding; mapped in channels that are incised into lacustrine deposits and older alluvial fan deposits (Qafy, Qaf_2, Qafo); wide shallow channels in the northern part of the quadrangle may represent stream channels that formed soon after the Lake Bonneville flood that collected and transported water and sediments from coalescing sheet flood events, dewatering surficial deposits, and/or groundwater-fed spring flow, as the channels diminish in width and depth upslope with no large feeder alluvial channels (McKean, 2020); thickness probably less than 15 feet (5 m).

Qaf_1 **Level-1 alluvial-fan deposits** (upper Holocene) – Poorly to moderately sorted pebble to cobble gravel, with boulders near bedrock sources, with a matrix of sand, silt, and clay; angular to subrounded clasts; medium to very thick bedded; deposited by debris flows and debris floods; mapped only in three small areas in the northeastern corner of the quadrangle; equivalent to the younger part of younger alluvial-fan deposits (Qafy) but differentiated because these small, active, discrete fans are not incised by younger channels, they overlie older alluvial fans and can be mapped separately; exposed thickness less than 15 feet (5 m).

Qaf_2 **Level-2 alluvial-fan deposits** (middle Holocene to upper Pleistocene) – Poorly to moderately sorted pebble to cobble gravel, with boulders near bedrock sources, with a matrix of sand, silt, and clay; angular to subrounded clasts; medium to very thick bedded; deposits are 5 to 20 feet (1.5–6 m) above modern incised drainages (Qaly); mapped in Tintic Davis Canyon and Chimney Rock Pass areas; no Lake Bonneville shorelines are present on these alluvial fans; equivalent to the older part of Qafy, but differentiated where deposits are graded to above modern stream level and can be mapped separately; exposed thickness less than 20 feet (6 m).

Qafy **Younger alluvial-fan deposits, undivided** (Holocene to upper Pleistocene?) – Poorly to moderately sorted, pebble to cobble gravel, with boulders near bedrock sources, with a matrix of sand, silt, and clay; grades downslope into mixtures of sand, silt, and clay on gentler slopes; clasts subangular to well rounded; forms coalesced aprons of post-Bonneville alluvial deposits; covers large areas of southern Cedar and Goshen Valleys; may include some undifferentiated thin Bonneville transgressive deposits or pre-Bonneville alluvial-fan deposits; Lake Bonneville shorelines are not present on these alluvial fans; thickness unknown, but likely up to several tens of feet thick.

Qafp **Alluvial-fan deposits, related to Provo shoreline and regressive phase of Lake Bonneville** (upper Pleistocene) – Poorly to moderately sorted, pebble to cobble gravel, with a matrix of sand, silt, and minor clay; clasts subangular to rounded; medium to very thick bedded; deposited by debris flows, debris floods, and stream flow; mapped in the northeastern part of the quadrangle where deposits have a fan-shaped morphology and grade downslope to the Provo shoreline and associated lacustrine sand and gravel (Qlsp) (see plate 1, section 25, T. 8 S., R. 2 W., Salt Lake Base Line and Meridian [SLBLM]); equivalent to the younger part of level-3 alluvial-fan deposits (Qaf_3) mapped elsewhere along the Wasatch Front (see unit af3 of Nelson and Personius, 1993); exposed thickness less than 15 feet (5 m).

Qafb **Alluvial-fan deposits, related to Bonneville shoreline and transgressive phase of Lake Bonneville** (upper Pleistocene) – Poorly to moderately sorted, pebble to cobble gravel, with boulders near bedrock sources, with a matrix of sand, silt, and minor clay; clasts subangular to rounded; medium to very thick bedded; deposited by debris flows, debris floods, and stream flow; appear graded to slightly below the Bonneville (highest) shoreline of Lake Bonneville; incised by post-Lake Bonneville young stream deposits (Qaly); mapped in two areas in the southeastern part of the quadrangle; equivalent to the older part of level-3 alluvial-fan deposits (Qaf_3) mapped elsewhere along the Wasatch Front (see unit af3 of Nelson and Personius, 1993); exposed thickness less than 15 feet (5 m).

Qafo **Older alluvial-fan deposits, pre-Lake Bonneville** (upper to middle Pleistocene?) – Poorly sorted, pebble to cobble gravel with boulders, with a matrix of sand, silt, and minor clay; subangular to subrounded clasts; forms dissected, stranded alluvial deposits in southern Cedar Valley that predate Lake Bonneville; locally etched by Bonneville shoreline; deposits are 20 to 50 feet (6–15 m) above younger incised drainages (Qaly, Qafy); locally may include some thin undifferentiated Bonneville transgressive deposits; thickness unknown, but likely up to several tens of feet thick.

Colluvial Deposits

Qc **Colluvial deposits** (Holocene to middle Pleistocene?) – Poorly to very poorly sorted, angular, clay- to boulder-size, locally derived sediment; clasts commonly angular to subangular, but includes some subrounded to rounded, recycled lacustrine gravel below the Bonneville shoreline; poorly stratified, deposited by slope wash and soil creep on moderate slopes, saddles, and in shallow depressions; most bedrock is covered by at least a thin veneer of colluvium, but only the larger, thicker (> 3 feet [1 m]) deposits are mapped; estimated thickness 0 to 20 feet (0–6 m).

Human-Derived Deposits

Qh **Fill and disturbed land** (historical) – Undifferentiated artificial fill and disturbed land related to the construction of small earthen dams for livestock watering ponds and gravel pit near Allens Ranch; only the larger areas of disturbed land are mapped; smaller watering ponds are not mapped due to map-scale limitations; thickness unknown.

Lacustrine Deposits

Deposits related to Lake Bonneville and Cedar Valley Lake: In Cedar Valley, deposits located below the elevation of the southern Cedar Valley threshold (McKean, 2020), which is between 4940 and 4950 feet (1506–1508 m), and likely include deposits of both Lake Bonneville transgressive and overflowing phases, as well as Cedar Valley Lake that stabilized (likely after the Bonneville flood) at about 4900 feet (1494 m) (see table 1). The Cedar Valley Lake shoreline was observed in Goshen Pass quadrangle to the north (McKean, 2020), but not identified in the Allens Ranch quadrangle.

Qls **Lacustrine sand and silt** (upper Pleistocene) – Moderately to well-sorted, subrounded to rounded, very fine to medium sand, silt, and clay; deposited in relatively shallow water nearshore; gastropod shells are locally common; mapped in the northern half of the quadrangle near and above the Cedar Valley Lake shoreline, up to the approximate Cedar Valley threshold elevation where the deposit may include both Lake Bonneville and subsequent Cedar Valley Lake deposits; locally may include unmapped thin eolian deposits; incised by younger Qaly and overlain by younger Qafy; estimated thickness 3 to 15 feet (1–5 m).

Deposits related to the Provo shoreline and regressive phase of Lake Bonneville: In Goshen Valley, deposits located below an elevation of about 4760 to 4790 feet (1450–1460 m), likely include overflowing and regressive phase deposits of Lake Bonneville (see table 1). Cedar Valley was isolated from Lake Bonneville after the Bonneville flood about 18 ka and became its own closed basin (Wambeam, 2001). Thus, Cedar Valley lacks Provo shoreline and regressive phase deposits, but contains Cedar Valley Lake deposits (McKean, 2020).

Qlsp **Lacustrine sand and silt** (upper Pleistocene) – Moderately to well-sorted, subrounded to rounded, fine to coarse sand and silt with minor pebbly gravel; thick to very thick bedded, commonly laminated with some ripple marks and scour features; gastropods locally common; deposited in relatively shallow water; mapped in one location east of Rattlesnake Pass (see plate 1, section 25, T. 8 S., R. 2 W., SLBLM); unit may include undifferentiated transgressive deposits; exposed thickness less than 15 feet (5 m).

Deposits related to the Bonneville shoreline and transgressive phase of Lake Bonneville: Mapped between the Bonneville and Provo shorelines. The Bonneville shoreline is at elevations from about 5140 to 5180 feet (1567–1579 m) in the Allens Ranch quadrangle (table 1).

Qlgb **Lacustrine gravel and sand** (upper Pleistocene) – Moderately to well-sorted, clast-supported pebble to cobble gravel with a matrix of sand and silt; thin to thick bedded; clasts commonly subrounded to rounded, but some deposits consist of poorly sorted, angular gravel derived from nearby bedrock outcrops; gastropods locally common in sandy lenses; beach gravels locally cemented with calcium carbonate; deposited below wave-cut benches close to the Bonneville shoreline, as spit-like deposits adjacent to bedrock outcrops in the northeastern corner of the quadrangle, and as accumulations of transgressive lacustrine gravel and sand bars in Cedar Valley; interbedded or laterally gradational with lacustrine sand and silt of the transgressive phase (Qlsb) and mixed lacustrine and alluvial deposits (Qla); thickness variable, some deposits likely greater than 40 feet (10 m).

Qlsb **Lacustrine sand and silt** (upper Pleistocene) – Moderately to well-sorted, subrounded to rounded, fine to coarse sand with silt and minor pebbly gravel; typically laminated; gastropods locally common; deposited in relatively shallow water nearshore, downslope from and laterally gradational with transgressive gravel and sand (Qlgb); estimated thickness less than 30 feet (10 m).

Spring Deposits

Qs **Spring deposit** (Quaternary?) – White to light-brown, cemented calcium carbonate deposit; thinly laminated with laminae from 0.8 to 0.4 inches (0.2–1 cm) thick; mapped in one location 4370 feet (1332 m) south of Chimney Rock (40.05002° N, 112.03916°

W); likely natural spring deposits accumulated in the Quaternary or earlier; may be related to travertine in the White Knoll Member (Tsw) in area of QTaf; small, unmapped deposits are likely present; age uncertain; thickness 3 to 15 feet (1–5 m).

Mixed-Environment Deposits

Qac **Alluvial and colluvial deposits, undivided** (Holocene to middle Pleistocene?) – Poorly to moderately sorted, generally poorly stratified, clay- to boulder-size, locally derived sediment; rounded to angular clasts; mapped where alluvium and colluvium (slopewash and soil creep) grade into one another or are intermixed and cannot be shown separately at map scale; mapped in drainages where stream and fan alluvium and colluvium from the sides of the drainage are intermixed; small, unmapped deposits are likely present in most small drainages; thickness less than 15 feet (5 m).

Qlay **Lacustrine and younger alluvial-fan deposits, undivided** (Holocene to upper Pleistocene) – Poorly to well-sorted sand, silt, clay, marl, and gravel; mapped below the Bonneville shoreline elevation on the distal margins of younger alluvial-fan deposits (Qafy) where lacustrine and alluvial sediments are intermixed and cannot be shown separately; distinguished from Qls and Qla by distinct parallel alluvial channel texture on 1939 aerial photographs (U.S. Department of the Interior, Bureau of Reclamation, 1939) and from Qafy by lower gradient of deposits; thickness likely less than 15 feet (5 m).

Qla **Lacustrine and alluvial deposits, undivided** (Holocene to upper Pleistocene) – Poorly to moderately sorted sand, silt, clay, marl, pebble gravel, and sandy gravel; mapped in areas of mixed alluvial and lacustrine deposits that cannot be shown separately at map scale, or because the deposits are gradational into each other, or thin patches of one unit overlie the other; estimated thickness less than 20 feet (6 m).

Stacked-Unit Deposits

Stacked units are used on this map to represent a number of surficial and bedrock units that are partially covered by lacustrine deposits of Lake Bonneville.

Qlsb/QTaf

Lacustrine sand and silt deposits related to the Bonneville shoreline and transgressive phase of Lake Bonneville over older alluvial-fan deposits (upper Pleistocene over lower Pleistocene? to Pliocene?) – A veneer of lacustrine sand and silt over older alluvial fan deposits (QTaf); mapped below the Bonneville shoreline in the Chimney Rock Pass area; lacustrine deposits are 0 to 15 feet (0–5 m) thick; estimated exposed thickness of QTaf in the quadrangle is likely tens of feet.

Qlgb/Tpc

Lacustrine gravel and sand related to the Bonneville shoreline and transgressive phase of Lake Bonneville over Pinyon Creek Conglomerate (upper Pleistocene over Oligocene?) – A veneer of lacustrine gravel and sand reworked from extensive underlying volcaniclastic deposits of the Pinyon Creek Conglomerate (Tpc) and other bedrock sources of volcanic and non-volcanic clasts; mapped below the Bonneville shoreline on the eastern part of the quadrangle; thickness of lacustrine deposits is variable; estimated exposed thickness of Tpc in the quadrangle is greater than 150 feet (50 m).

Qlsb/Tpc

Lacustrine sand and silt deposits related to the Bonneville shoreline and transgressive phase of Lake Bonneville over Pinyon Creek Conglomerate (upper Pleistocene over Oligocene?) – A veneer of lacustrine sand and silt over volcaniclastic deposits of the Pinyon Creek Conglomerate (Tpc); mapped below the Bonneville shoreline in the Chimney Rock Pass area; lacustrine deposits are 0 to 15 feet (0–5 m) thick; estimated exposed thickness of Tpc in the Chimney Rock Pass area is 10 to 30 feet (3–10 m) but can be greater than 150 feet (50 m) in the quadrangle.

Qlgb/Mgb

Lacustrine gravel and sand related to the Bonneville shoreline and transgressive phase of Lake Bonneville over Great Blue Limestone, undifferentiated (upper Pleistocene over Upper Mississippian) – Great Blue Limestone is partially concealed with a discontinuous veneer of lacustrine deposits consisting of sand, silt, clay, and pebble gravel; mapped in one location on the northeastern quadrangle boundary with Goshen Pass quadrangle; small bedrock knobs are included in the unit and not mapped separately due to map-scale limitations; lacustrine deposits are 0 to 15 feet (0–6 m) thick.

Major unconformity

QUATERNARY/TERTIARY

QTaf **Oldest alluvial-fan deposits** (lower Pleistocene? to Pliocene?) – Poorly sorted, pebble to cobble gravel with boulders, with a matrix of sand, silt, and minor clay; composed of Paleozoic limestone and dolomite clasts; locally includes volcanic clasts from East Tintic volcanic field; subangular to rounded clasts; forms highly dissected, stranded alluvial deposits on the north and east flanks of the Selma Hills (figure 2); appears to overlie the Pinyon Creek Conglomerate; thickness unknown, but likely up to several tens of feet.

Unconformity

NEOGENE-PALEOGENE (TERTIARY)

Tj **Jasperoid** (Tertiary?) – Silicic replacement breccia, commonly very dark red to grayish brown; forms ledges, pods, and rubbly exposures that vary from all jasperoid to outcrops with varying degrees of fractured limestone or dolomitic host rock still visible; found in numerous small areas throughout the quadrangle; smaller jasperoid breccias are not mapped due to map-scale constraints; outcrops are typically more resistant than surrounding bedrock and form ridges; locally appears to replace Packard Quartz Latite but not Latite Ridge Latite, which may indicate the age of some of the alteration; variable length from 3 to 300 feet (1–90 m) and thickness is 3 to 30 feet (1–10 m).

MIOCENE

Whole-rock geochemical data for igneous units in the Allens Ranch quadrangle are available in McKean and others (2013). Geochemical rock names are from the total alkali-silica classification diagram for igneous rocks (Le Bas and others, 1986); see figures 6 and 7 for geochemical diagrams. Table 2 gives K-Ar and $^{40}Ar/^{39}Ar$ ages of volcanic units, table 3 gives average compositions of volcanic units, and table 4 summarizes volcanic rock samples, sample numbers, and map numbers as shown on plate 1. Numerous formally and informally named volcanic units are discussed in this section, and the distinction between formal and informal members of a formation is shown by capitalization; formal member names are capitalized, informal member names are not.

Tb **Mosida Basalt** (lower Miocene) – Medium-dark-gray, weathering to light-olive-gray, gray, and reddish brown, porphyritic, potassic trachybasalt lava flow; phenocrysts (10% to 20%) of olivine, plagioclase, and clinopyroxene in a fine-grained groundmass; olivine commonly altered to iddingsite and appears as rust-colored blebs; forms ledges; mapped as isolated knobs in the northeast part of the quadrangle and east of Chimney Rock Pass; locally vesicular (figure 8) to scoriaceous; locally the base is altered to a light gray color (McKean, 2020); unconformably overlies the White Knoll Member (Tsw) and/or breccia member (Tsb) of the Soldiers Pass Formation; vent probably located near Soldiers Pass (Biek and others, 2009); its trace element pattern lacks Nb, Ti, and Pb anomalies (figure 7) that are present in all the older volcanic rocks of the area, indicating that the Mosida Basalt is not subduction-related but rather extension-related as proposed by Christiansen and others (2007); $^{40}Ar/^{39}Ar$ isochron age on groundmass from Allens Ranch quadrangle is 19.74 ± 0.05 Ma (McKean, 2011; Christiansen and others, 2013), this age correlates well with Mosida Basalt samples dated using $^{40}Ar/^{39}Ar$ methods by Christiansen and others (2007) that were found to be 19.47 ± 0.14 and 19.65 ± 0.17 Ma (table 2); 0 to 40 feet (0–12 m) thick in the quadrangle; Biek and others (2009) report a thickness in the Soldiers Pass quadrangle of 0 to 120 feet (0–35 m).

Unconformity

MIOCENE-OLIGOCENE

Tpc **Pinyon Creek Conglomerate** (Oligocene? to lower Miocene?) – Moderately to poorly sorted volcanic conglomerate mainly of pebble to boulder-size volcanic clasts in a matrix of volcaniclastic fine ash, silt, and sand; reddish brown or gray and well-rounded clasts composed entirely of volcanic rock; distinctly bedded throughout with individual beds ranging from 1.6 to 10 feet (0.5–3 m) thick (see figure 9), some beds consist primarily of fine ash and small fragments, others contain both fine and coarse fragments (Morris and Lovering, 1979); forms slopes in the southeast part of the quadrangle; Pinyon Creek Conglomerate volcanic clasts were probably eroded from Laguna Springs Volcanic Group lava flows based on field observations of outcrop patterns, phenocrysts (assemblages, size, abundances), rock texture, and presence of glass and non-glassy lava types; additionally, a volcanic clast in the Pinyon Creek Conglomerate has been chemically identified as Laguna Springs Volcanic Group (sample AR-808, McKean and others, 2013); likely deposited as alluvial fans and/or alluvial aprons sourced from adjacent Laguna Springs Volcanic Group (Morris and Lovering, 1979); no direct age data, but stratigraphically beneath the Miocene (18 Ma) Silver Shield Quartz Latite and laterally equivalent to or above the Oligocene Laguna Springs Volcanic Group in the Eureka and Allens Ranch quadrangles, which indicates an approximate Oligocene age (Laughlin and others, 1969; Morris and Lovering, 1979); estimated exposed thickness in Allens Ranch quadrangle is greater than 150 feet (50 m), and in the East Tintic Mountains the reported thickness is 0 to 1000+ feet (0–305+ m) (Morris and Lovering, 1979).

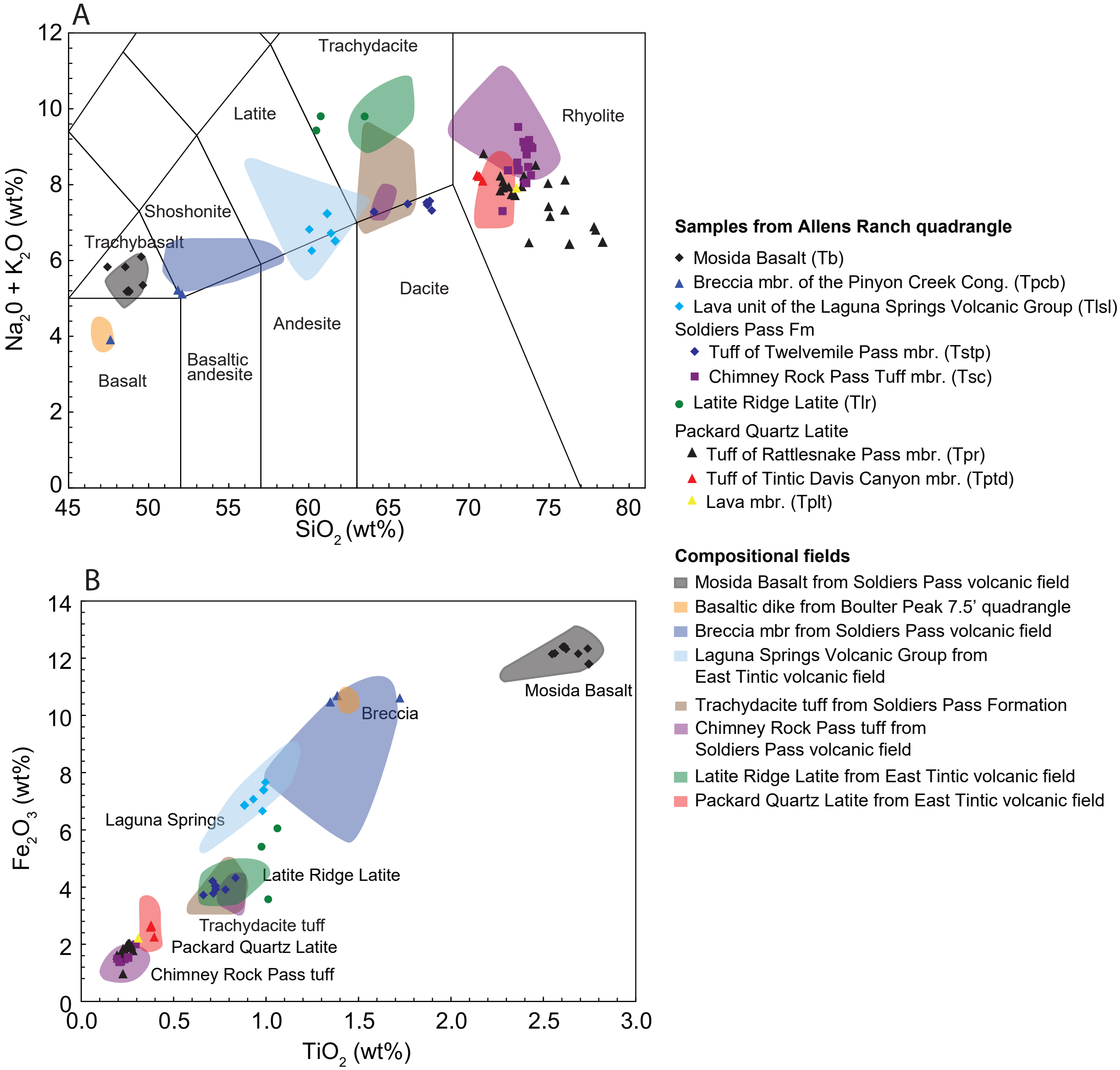

Figure 6. *Major-element classification and chemical discrimination diagrams for the volcanic rocks of the Allens Ranch quadrangle and nearby East Tintic and Soldiers Pass volcanic fields.* ***(A)*** *Total alkali-silica classification for igneous rocks of the Goshen Pass quadrangle (values have been normalized to 100% on a volatile-free basis), classification diagram from Le Bas and others (1986).* ***(B)*** *Fe-Ti chemical discrimination diagram showing the variation of volcanic units in the quadrangle and surrounding volcanic fields. For both A and B, see McKean and others (2013) for Allens Ranch quadrangle whole-rock geochemical data (shown as point data). For both A and B, the compositional fields (shown as colored areas) are the approximate limit of previously published geochemical compositions for a given unit. Sources of East Tintic volcanic field data from Morris and Lovering (1979), Kim (1997, 1999), Moore (1993), and Moore and others (2007); Soldiers Pass volcanic field data are from Christiansen and others (2007) and Christiansen (2009).*

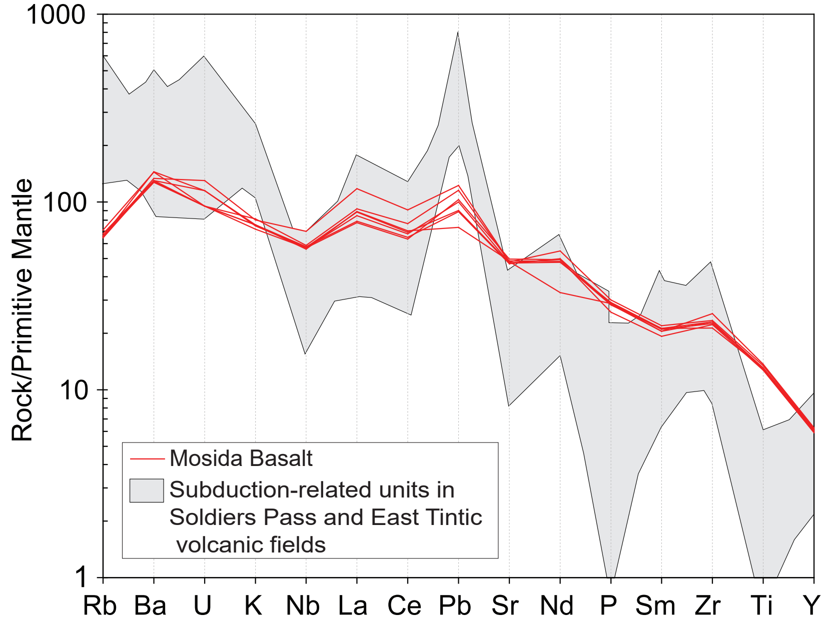

Figure 7. *Trace-element patterns for the volcanic rocks of the Allens Ranch quadrangle and nearby East Tintic and Soldiers Pass volcanic fields. Plot shows older subduction-related units (*Tlsl, Tstp, Tsc, Tlr, Tpr, Tptd*, and* Tplt*) in gray versus the red lines that represent the Miocene extension-related Mosida Basalt (*Tb*). Subduction-related units show characteristic Nb, Pb, and Ti anomalies and are enriched in more soluble elements Rb, Ba, U, and Pb. Sources of East Tintic volcanic field data are from Kim (1997, 1999), Moore (1993), and Moore and others (2007), while the Soldiers Pass volcanic field data are from Christiansen and others (2007). See McKean and others (2013) for Allens Ranch quadrangle whole-rock geochemical data.*

OLIGOCENE

Tpcb **Breccia member of the Pinyon Creek Conglomerate** (Oligocene?) – In two small areas, the Pinyon Creek Conglomerate contains interbeds of intermediate composition volcanic rocks; one locality is a pillowed shoshonitic lava flow, the other is a poorly exposed basaltic dike or lava flow.

At Chimney Rock Pass, the shoshonite interbedded within the Pinyon Creek Conglomerate is medium-dark-gray vesicular pillow lava with abundant hyaloclastite fragments; locally calcium carbonate has precipitated between pillows (see figure 10), sometimes as fairly coarse-grained, sparry calcite; main phenocrysts (~10%) are olivine, but quartz grains about 0.08 inch (2 mm) across are present and are probably xenocrysts, olivine is commonly altered to iddingsite and appears as rust-colored blebs; the pillow lava interfingers with the alluvial-fan deposits of the Pinyon Creek Conglomerate; thickness of the pillow lava breccia unit is estimated to be less than 30 feet (10 m).

The basalt dike or lava flow forms a small (30 feet [10 m] wide) outcrop on the western side of Chimney Rock Pass and is composed of a fine-grained groundmass with phenocrysts (~10%) of olivine, sparse micro-phenocrysts of amphibole, and quartz xenocrysts; olivine phenocrysts are commonly altered to iddingsite; basalt is silica-undersaturated and is geochemically similar to a dike on Gardison Ridge in the Boulter Peak 7.5' quadrangle about 4 miles (6.5 km) to the west-southwest from the basalt outcrops (Allen, 2012; McKean and others, 2013); contact relations are unclear, so the Tpcb outcrop could be a small dike or a mostly buried lava flow.

Laguna Springs Volcanic Group – Morris and Lovering (1979) mapped the group as basal tuff, lower flow series, middle tuff and agglomerate, and upper flow series. Formally, the group includes three formations: North Standard Latite, Pinyon Queen Latite, and Tintic Delmar Latite (Morris and Lovering, 1979); however, these formations are virtually indistinguishable from each other (Pampeyan, 1989) and have not been subdivided for this study, except into informal tuff (Tlsa) and lava (Tlsl) units.

Tlsa, Tlsl

Laguna Springs Volcanic Group, tuff and lava units (Oligocene) – Andesite to trachyandesite ash-flow tuffs (Tlsa) and lava flows (Tlsl); tuffs are dark reddish brown, and the lavas range in color from reddish-brown to purplish gray to gray; lavas form ledges and cliffs that are dense and commonly vitrophyric with large phenocrysts (30%–40%) of plagioclase,

Table 3. *Average whole-rock geochemical compositions of volcanic units from the Allens Ranch quadrangle.*

Formation			**Pinyon Creek Conglomerate**		**Soldiers Pass Formation**			**Packard Quartz Latite**		
Member	**Mosida Basalt**	**lava unit of Laguna Springs Volcanic Group**	**pillow lava breccia member**	**lava breccia member**	**Chimney Rock Pass Tuff Member**	**tuff of Twelvemile Pass mbr**	**Latite Ridge Latite**	**tuff of Rattlesnake Pass mbr**	**lava member**	**tuff of Tintic Davis Canyon mbr**
Map Unit	Tb	Tlsl	Tpcb	Tpcb	Tc	Ttp	Tlr	Tpr	Tplt	Tptd
Normalized to 100% on a volatile-free basis										
$Si0_2$	48.94	60.53	51.95	47.60	73.31	66.67	61.57	73.72	72.96	70.65
$Ti0_2$	2.63	0.97	1.37	1.72	0.22	0.74	1.02	0.24	0.31	0.38
AI_20_3	16.79	15.52	14.77	15.31	13.84	15.92	17.64	13.65	14.58	14.94
Fe_20_3	12.27	7.13	10.56	10.59	1.50	3.97	5.01	1.80	2.20	2.51
MnO	0.19	0.13	0.21	0.15	0.06	0.09	0.11	0.06	0.08	0.10
MgO	4.61	2.92	5.28	7.58	0.76	1.00	1.27	0.76	0.40	0.77
CaO	8.55	5.83	9.98	12.28	1.59	3.51	3.37	1.93	1.53	2.35
Na_20	3.23	3.40	3.16	2.25	2.69	3.31	3.89	3.18	2.84	3.39
K20	2.21	3.20	1.99	1.65	5.98	4.58	5.78	4.58	5.06	4.79
P_20_5	0.59	0.37	0.73	0.86	0.05	0.20	0.34	0.08	0.06	0.11
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Sc (ppm)	20	14	28	0	1	13	11	3	18	4
V	244	118	259	275	11	48	104	16	6	13
Cr	26	38	578	101	5	8	10	5	0	2
Ni	16	11	175	40	1	3	6	1	0	2
Cu	29	21	53	91	2	9	21	1	8	4
Zn	97	69	89	88	28	50	85	23	37	32
Ga	23	19	19	20	13	18	23	12	20	14
Rb	40	97	46	29	212	149	222	195	126	117
Sr	960	615	1134	1527	214	600	798	252	386	450
Y	26	28	29	25	19	33	36	17	21	22
Zr	241	202	233	272	146	341	365	118	226	214
Nb	39	13	49	54	15	16	26	16	14	13
Ba	885	946	2105	2815	888	1408	2087	664	2510	2880
La	58	52	103	139	52	60	84	34	113	86
Ce	121	103	209	274	98	119	165	68	212	158
Nd	59	45	90	111	34	52	82	29	69	53
Sm	9	9	14	20	7	9	12	6	12	11
Pb	7	19	14	15	32	21	33	28	26	23
Th	6	15	14	14	27	20	43	23	15	18
U	2	4	4	3	8	5	10	6	0	4

Notes: Major oxides reported in weight percent and trace elements reported in parts per million (ppm) by X-ray fluorescence spectrometry at Brigham Young University

Table 4. *Summary of volcanic rock samples from the Allens Ranch quadrangle.*

Map Number	Sample Number	Map Unit	Unit Name	Rock Type	Rock Name	Latitude	Longitude
AR1	AR-608	Tb	Mosida Basalt	lava flow	trachybasalt	40.10982	-112.02232
AR2	AR-708	Tb	Mosida Basalt	lava flow	trachybasalt	40.10640	-112.01300
AR3	AR-AE-09	Tb	Mosida Basalt	lava flow	trachybasalt	40.06853	-112.00843
AR4	AR-JRY-08-01	Tb	Mosida Basalt	lava flow	trachybasalt	40.11002	-112.02186
AR5	AR-JRY-08-02	Tb	Mosida Basalt	lava flow	trachybasalt	40.11057	-112.00598
AR6	AR-TLA-08	Tb	Mosida Basalt	lava flow	trachybasalt	40.06974	-112.00763
AR7	AR-2008	Tpcb	pillow lava breccia member of the Pinyon Creek Conglomerate	pillow lava breccia	shoshonite	40.06458	-112.04370
AR8	AR-2506	Tpcb	pillow lava breccia member of the Pinyon Creek Conglomerate	pillow lava breccia	shoshonite	40.06450	-112.04358
AR9	AR-808	Tpc	clast in the Pinyon Creek Conglomerate	clast	latite	40.10505	-112.01107
AR10	AR-109	Tpc	flow or clast in the Pinyon Creek Conglomerate	lava	dacite	40.06677	-112.03559
AR11	AR-209	Tpcb	lava breccia member of the Pinyon Creek Conglomerate	lava/dike?	basalt	40.06084	-112.05934
AR12	AR-105	Tsc	Chimney Rock Pass tuff Member of Soldiers Pass Formation	ash-flow tuff	rhyolite	40.06252	-112.02838
AR13	AR-1108	Tsc	Chimney Rock Pass tuff Member of Soldiers Pass Formation	ash-flow tuff	rhyolite	40.06179	-112.03631
AR14	AR-205	Tsc	Chimney Rock Pass tuff Member of Soldiers Pass Formation	ash-flow tuff	rhyolite	40.06252	-112.02838
AR15	AR-305	Tsc	Chimney Rock Pass tuff Member of Soldiers Pass Formation	ash-flow tuff	rhyolite	40.06252	-112.02838
AR16	AR-308	Tsc	Chimney Rock Pass tuff Member of Soldiers Pass Formation	ash-flow tuff	rhyolite	40.08971	-112.02091
AR17	AR-AD-06	Tsc	Chimney Rock Pass tuff Member of Soldiers Pass Formation	ash-flow tuff	rhyolite	40.06213	-112.03587
AR18	AR-CJS-09	Tsc	Chimney Rock Pass tuff Member of Soldiers Pass Formation	ash-flow tuff	rhyolite	40.06194	-112.03672
AR19	AR-JR-06	Tsc	Chimney Rock Pass tuff Member of Soldiers Pass Formation	ash-flow tuff	rhyolite	40.06300	-112.02800
AR20	AR-NKA-06	Tsc	Chimney Rock Pass tuff Member of Soldiers Pass Formation	ash-flow tuff	rhyolite	40.06213	-112.03587
AR21	AR-PDP-09	Tsc	Chimney Rock Pass tuff Member of Soldiers Pass Formation	ash-flow tuff	rhyolite	40.06086	-112.02797
AR22	AR-PJG-09	Tsc	Chimney Rock Pass tuff Member of Soldiers Pass Formation	ash-flow tuff	rhyolite	40.06208	-112.02893
AR23	AR-REH-06	Tsc	Chimney Rock Pass tuff Member of Soldiers Pass Formation	ash-flow tuff	rhyolite	40.06218	-112.03243
AR24	AR-SES-09	Tsc	Chimney Rock Pass tuff Member of Soldiers Pass Formation	ash-flow tuff	rhyolite	40.06176	-112.05778
AR25	AR-TAC-09	Tsc	Chimney Rock Pass tuff Member of Soldiers Pass Formation	ash-flow tuff	rhyolite	40.06075	-112.03130
AR26	AR-TDW-06	Tsc	Chimney Rock Pass tuff Member of Soldiers Pass Formation	ash-flow tuff	rhyolite	40.06200	-112.03672
AR27	AR-RLH-08	Tlsl	lava of Laguna Springs Volcanic Group	lava flow	latite	40.00190	-112.08009
AR28	AR-1608	Tlsl	lava of Laguna Springs Volcanic Group	lava flow	andesite	40.00682	-112.02439
AR29	AR-805	Tlsl	lava of Laguna Springs Volcanic Group	lava flow	latite	40.00753	-112.07502
AR30	AR-1408	Tstp	tuff of Twelvemile Pass member of the Soldiers Pass Formation	welded tuff	trachydacite	40.06232	-112.05815
AR31	AR-2606	Tstp	tuff of Twelvemile Pass member of the Soldiers Pass Formation	welded tuff	dactite	40.06342	-112.04957
AR32	AR-2706	Tstp	tuff of Twelvemile Pass member of the Soldiers Pass Formation	welded tuff	dacite	40.06342	-112.04957

Table 4. *continued.*

Map Number	Sample Number	Map Unit	Unit Name	Rock Type	Rock Name	Latitude	Longitude
AR33	AR-PG-09	Tstp	tuff of Twelvemile Pass member of the Soldiers Pass Formation	welded tuff	dacite	40.06142	-112.03807
AR34	AR-SAM-06	Tstp	tuff of Twelvemile Pass member of the Soldiers Pass Formation	welded tuff	dacite	40.06100	-112.03807
AR35	AR-KLG-08	Tlr	Latite Ridge Latite	welded tuff	trachydacite	40.00777	-112.05074
AR36	AR-S7608	Tlr	Latite Ridge Latite	welded tuff	trachydacite	40.01076	-112.05897
AR37	AR-1808	Tlr	Latite Ridge Latite	welded tuff	trachydacite	40.01215	-112.08705
AR38	AR-1508	Tp	tuff of Rattlesnake Pass member of the Packard Quartz Latite	ignimbrite	rhyolite	40.06778	-112.05450
AR39	AR-208	Tp	tuff of Rattlesnake Pass member of the Packard Quartz Latite	ignimbrite	rhyolite	40.09148	-112.01683
AR40	AR-405	Tp	tuff of Rattlesnake Pass member of the Packard Quartz Latite	ignimbrite	rhyolite	40.06778	-112.05194
AR41	AR-505	Tp	tuff of Rattlesnake Pass member of the Packard Quartz Latite	ignimbrite	rhyolite	40.07315	-112.04231
AR42	AR-605	Tp	tuff of Rattlesnake Pass member of the Packard Quartz Latite	ignimbrite	rhyolite	40.06800	-112.02961
AR43	AR-905	Tp	tuff of Rattlesnake Pass member of the Packard Quartz Latite	ignimbrite	rhyolite	40.08611	-112.12444
AR44	AR-APM-08	Tp	tuff of Rattlesnake Pass member of the Packard Quartz Latite	ignimbrite	rhyolite	40.07240	-112.04259
AR45	AR-BL-06	Tp	tuff of Rattlesnake Pass member of the Packard Quartz Latite	ignimbrite	rhyolite	40.07027	-112.04675
AR46	AR-BLB-06	Tp	tuff of Rattlesnake Pass member of the Packard Quartz Latite	ignimbrite	rhyolite	40.06562	-112.05348
AR47	AR-DD-09	Tp	tuff of Rattlesnake Pass member of the Packard Quartz Latite	ignimbrite	rhyolite	40.06766	-112.03317
AR48	AR-DPL-09	Tp	tuff of Rattlesnake Pass member of the Packard Quartz Latite	ignimbrite	rhyolite	40.07256	-112.04160
AR49	AR-JL-09	Tp	tuff of Rattlesnake Pass member of the Packard Quartz Latite	ignimbrite	rhyolite	40.06782	-112.03417
AR50	AR-JSC-08	Tp	tuff of Rattlesnake Pass member of the Packard Quartz Latite	ignimbrite	rhyolite	40.00981	-112.05243
AR51	AR-ML-09	Tp	tuff of Rattlesnake Pass member of the Packard Quartz Latite	ignimbrite	rhyolite	40.06811	-112.03203
AR52	AR-MP-06	Tp	tuff of Rattlesnake Pass member of the Packard Quartz Latite	ignimbrite	rhyolite	40.07348	-112.04096
AR53	AR-NJ-06	Tp	tuff of Rattlesnake Pass member of the Packard Quartz Latite	ignimbrite	rhyolite	40.07146	-112.04427
AR54	AR-RWB-09	Tp	tuff of Rattlesnake Pass member of the Packard Quartz Latite	ignimbrite	rhyolite	40.05825	-112.06008
AR55	AR-S30409	Tp	tuff of Rattlesnake Pass member of the Packard Quartz Latite	ignimbrite	rhyolite	40.06975	-112.12433
AR56	AR-SDF-06	Tp	tuff of Rattlesnake Pass member of the Packard Quartz Latite	ignimbrite	rhyolite	40.06836	-112.04829
AR57	AR-TPW-06	Tp	tuff of Rattlesnake Pass member of the Packard Quartz Latite	ignimbrite	rhyolite	40.06404	-112.04571
AR58	AR-107	Tptd	tuff of Tintic Davis Canyon member of the Packard Quartz Latite	vitrophyre	rhyolite	40.00937	-112.09625
AR59	AR-108	Tptd	tuff of Tintic Davis Canyon member of the Packard Quartz Latite	vitrophyre	rhyolite	40.00937	-112.09626
AR60	AR-1708	Tptd	tuff of Tintic Davis Canyon member of the Packard Quartz Latite	vitrophyre	rhyolite	40.00962	-112.09603
AR61	AR-TCH-08	Tptd	tuff of Tintic Davis Canyon member of the Packard Quartz Latite	vitrophyre	rhyolite	40.00956	-112.09665

Notes:
Location data are based on NAD83.
Whole-rock geochemical data for igneous units in the Allens Ranch quadrangle are available in McKean and others (2013).
Geochemical rock names are from the total alkali-silica classification diagram for igneous rocks (see figure 6).
Samples collected by authors, numerous students of Eric Christiansen, Bart Kowallis, and BYU Geology Field Camp students over many years.

Figure 8. *Weathered outcrop of Mosida Basalt (Tb) lava flow, in Soldiers Pass quadrangle (40.16375° N, 111.98576° W, NAD83); rock hammer for scale. The basalt unconformably overlies the White Knoll Member (Tsw) and/or breccia member (Tsb) of the Soldiers Pass Formation, not shown here.*

Figure 9. *Exposure of Pinyon Creek Conglomerate (Tpc; view looking north) showing a dominantly fine-grained matrix, volcanic clasts ranging from 1.5 to 10 feet (0.5–3 m) in diameter, and east-dipping bedding. Location is at the old railway tunnel on the southeast boundary of the quadrangle.*

sanidine, biotite, hornblende, and clinopyroxene (see figure 11); tuffs have phenocrysts (10%–20%) of plagioclase, biotite, and hornblende, are typically poorly welded and crop out very poorly as slope formers; mapped in the southern part of the quadrangle; lava was dated using sanidine by $^{40}Ar/^{39}Ar$ methods at 32.66 ± 0.03 Ma (sample AR-1608; Christiansen and others, 2013), see table 2 for additional ages; approximate tuff thickness less than 300 feet (<100 m) and lava thickness less than 650 feet (<200 m).

OLIGOCENE-EOCENE

Soldiers Pass Formation – Volcanic, lake, and hot-spring deposits include, in descending order: White Knoll Member, breccia member, andesite member, tuff of Twelvemile Pass member (new informal member), Chimney Rock Pass Tuff Member, and trachydacite tuff member (Christiansen and others, 2007). Only the White Knoll Member (Tsw), tuff of Twelvemile Pass member (Tstp), and Chimney Rock Pass Tuff Member (Tsc) are located in the Allens Ranch quadrangle.

Tsw **Soldiers Pass Formation, White Knoll Member** (lower Oligocene to upper Eocene) − White and pale yellowish orange, yellowish-gray-weathering limestone with interbedded very pale orange, white, and pale-red claystone (Biek and others, 2009); bedding is laminated to medium to indistinct; locally contains thin, light-gray pyroclastic-fall beds, altered to clay, and the limestone is locally sandy; deposited in a shallow lake over paleotopography developed on Paleogene volcanic rocks and Paleozoic strata (Biek and others, 2009); locally exhibits verti-

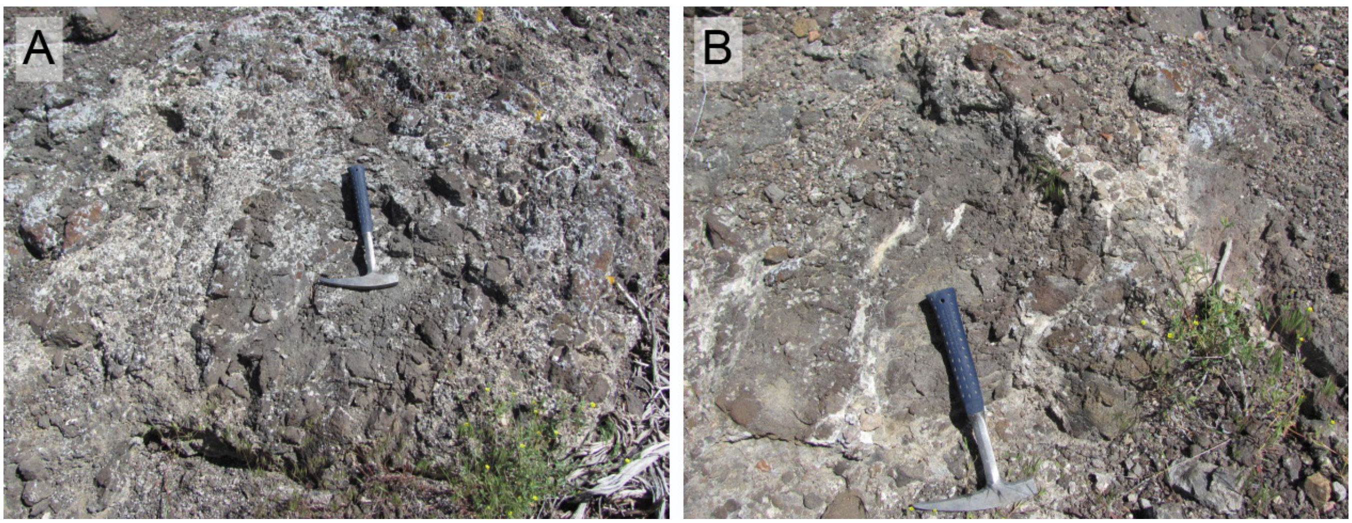

Figure 10. (A) *Pillow lava in breccia member (Tpcb) of the Pinyon Creek Conglomerate indicates deposition in water, with white carbonate precipitated between pillows.* ***(B)*** *Close-up photograph. Photographs taken at Chimney Rock Pass.*

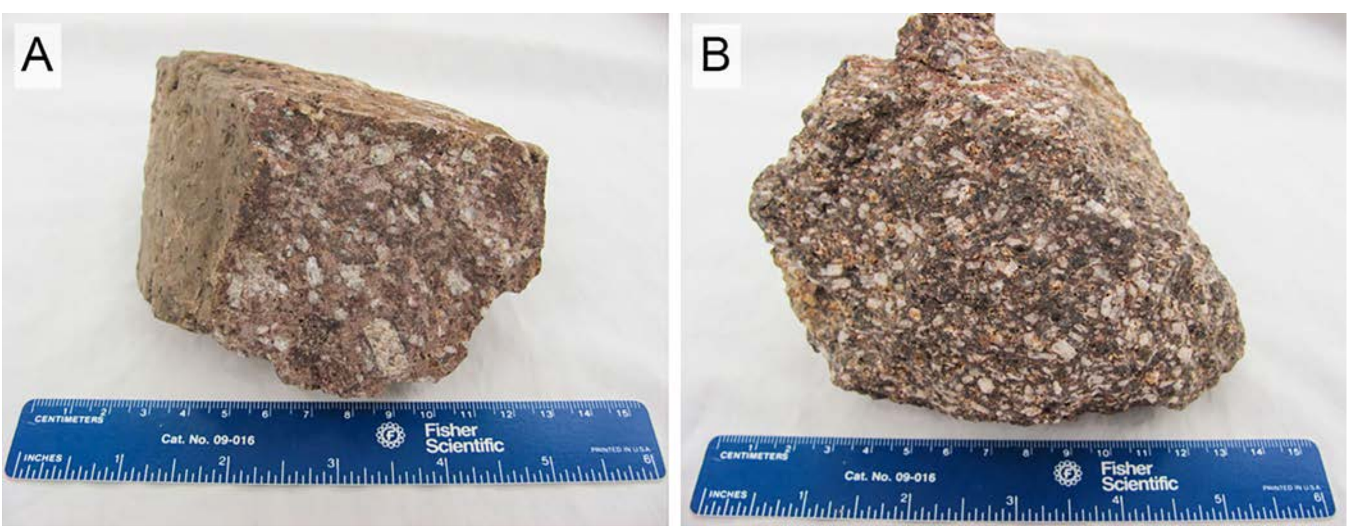

Figure 11. (A) *Hand sample of lava unit (Tlsl) of Laguna Springs Volcanic Group, showing abundant phenocrysts (30%–40%) including characteristically large phenocrysts of plagioclase.* ***(B)*** *Fresh surface, opposite side of sample.*

cal laminae of travertine and algal laminations suggestive of spring deposits (Biek and others, 2009); interfingers with the breccia member (Tsb) in the Goshen Pass (McKean, 2020) and Soldiers Pass (Biek and others, 2009) quadrangles; mapped only in the northeastern corner of the quadrangle as a slope beneath the more resistant Mosida Basalt; age about 33.7 Ma from coeval breccia member (Christiansen and others, 2007); greater than 20 feet (6 m) thick in the quadrangle; Biek and others (2009) reported a thickness in the Soldiers Pass quadrangle of 0 to 240 feet (0–75 m).

EOCENE

Tstp **Soldiers Pass Formation, tuff of Twelvemile Pass member** (upper Eocene) – Reddish-brown to dark reddish-brown, densely welded dacite to trachydacitic tuff; tuff contains flattened pumice lapilli (5%–10%); locally, the lapilli are 2 to 8 inches (6–20 cm) long and typically are 0.4 to 0.8 inches (1–2 cm) thick (see figure 12); phenocrysts (10%–20%) of plagioclase, biotite, hornblende, and clinopyroxene; we have assigned this welded tuff to the Soldiers Pass Formation because its geochemistry is very similar to the trachydacite tuff member of the Soldiers Pass Formation (figure 7) (Christiansen and others, 2007); mapped at Twelvemile Pass and Chimney Rock Pass on resistant knobs; plagioclase $^{40}Ar/^{39}Ar$ age from Chimney Rock Pass of 34.62 ± 0.16 Ma (table 2) (McKean, 2011; Christiansen and others, 2013); exposed thickness 15 to 50 feet (5–15 m).

Tsc **Soldiers Pass Formation, Chimney Rock Pass Tuff Member** (upper Eocene) – Gray to light-gray, poorly welded rhyolite ash-flow tuff; contains abundant pumice clasts (~15%) about 0.4 to 2 inches (1–5 cm) in diameter and lithic fragments (<5%) of 0.4 to 1.8 inches (1–4.5 cm); small phenocrysts (~10%) of quartz, sanidine, plagioclase, and biotite (see figure 13); type locality is at Chimney Rock, also mapped at Twelvemile Pass and Chimney Rock Pass and low-lying areas in the northeastern part of the quadrangle where the unit forms isolated knobs and ridges; Christiansen and others (2007) reported an $^{40}Ar/^{39}Ar$ age of 34.7 ± 0.07 Ma, and sample AR-1108 from the Allens Ranch quadrangle had a similar $^{40}Ar/^{39}Ar$ age of 34.61 ± 0.02 Ma (table 2) (Christiansen and others, 2013); thickness 10 to 80 feet (3–25 m); Biek and others (2009) reported an exposed thickness in the Soldiers Pass quadrangle of as much as 60 feet (20 m).

Tlr **Latite Ridge Latite** (upper Eocene) – Dark reddish-brown to brown, densely welded ignimbrite; phenocrysts (15%–20%) of plagioclase, biotite, and clinopyroxene, and is rich in lithics (15%–20%, ~0.4 inch [1 cm]), ash (10%–15%), and black flattened nonvesicular cognate inclusions (2 to 6 inches [5–15 cm] diameter) (see figure 14); mapped in the southern part of the quadrangle where it forms slopes and ridges; $^{40}Ar/^{39}Ar$ age of 34.64 ± 0.17 Ma from the nearby area (table 2) (UGS and NMGRL, 2007); thickness 0 to 65 feet (0–20 m).

Packard Quartz Latite – Morris and Lovering (1979) reported that the Packard Quartz Latite includes a basal tuff, a lower vitrophyre, a massive lava flow unit, and an upper vitrophyre in the Eureka quadrangle. However, Morris and Lovering (1979) did not map the Packard units separately and more work is needed to better understand them. In the East Tintic Mountains additional ash-flow tuffs have been identified in the Packard (Moore and others, 2007; McKean, 2011; Allen, 2012). $^{40}Ar/^{39}Ar$ analysis of sanidine in these ash-flow tuffs (Tpr and Tptd) in the Allens Ranch quadrangle yielded ages of 35.08 ± 0.03 Ma and 35.21± 0.03 Ma, respectively (table 2) (McKean, 2011; Christiansen and others, 2013). West of the Allens Ranch quadrangle, in the southeastern corner of the Boulter Peak quadrangle, a rhyolite lava member of the Packard above a lava flow breccia yielded an $^{40}Ar/^{39}Ar$ sanidine radiometric age of 35.25 ± 0.04 Ma (table 2) (Allen, 2012; Christiansen and others, 2013). In the Allens Ranch quadrangle we have identified three informal members (descending): tuff of Rattlesnake Pass member, tuff of Tintic Davis Canyon member, and the lava flow and tuff member.

Tpr **Packard Quartz Latite, tuff of Rattlesnake Pass member** (upper Eocene) – Light gray to pink, non-welded to welded rhyolite ignimbrite; with large and abundant phenocrysts (30%–40%) of quartz, sanidine, plagioclase, biotite, and characteristic bipyramids of quartz (see figure 15); contains pumice (1%–5%, 0.4 to 1.5 inches [1–4 cm]) and lithic (volcanic and carbonate) fragments (1%–5%, 0.4 to 1.5 inches [1–4 cm]), however, the pumice and lithic fragments are not as abundant as in unit Tsc; locally silicified; forms ledges and slopes; mapped throughout the quadrangle typically at the base of most volcanic outcrops and on the margins of southern Cedar Valley; $^{40}Ar/^{39}Ar$ radiometric dating of the sanidine showed the unit to be 35.08 ± 0.03 Ma (table 2) (sample AR-908; McKean, 2011; Christiansen and others, 2013); thickness 0 to 330 feet (0–100 m).

Tptd **Packard Quartz Latite, tuff of Tintic Davis Canyon member** (upper Eocene) – Dark gray to black vitrophyric rhyolite tuff with large amounts of glassy matrix (50%–60%); pheno-

***Figure 12.** Tuff of Twelvemile Pass member of the Soldiers Pass Formation (Tstp) is a densely welded tuff with reddish-brown to dark reddish-brown matrix and flattened pumice lapilli with dark glass. Photograph from the western side of Chimney Rock Pass.*

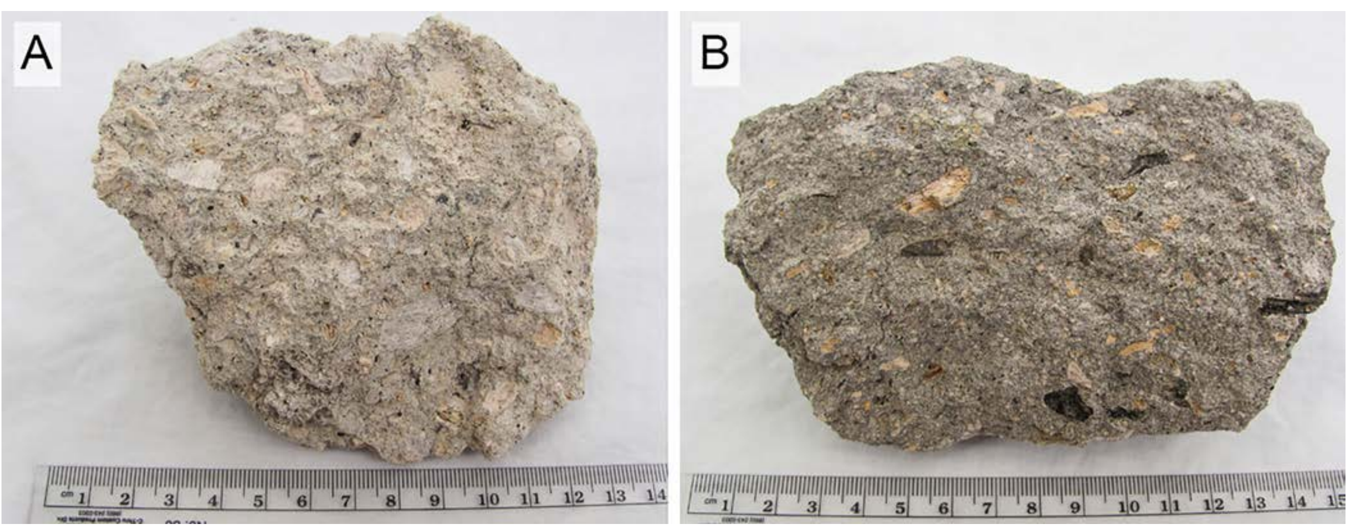

***Figure 13.** Two hand samples **(A and B)** of the Chimney Rock Pass Tuff Member of the Soldiers Pass Formation (Tsc) show its characteristic abundant pumice fragments and lithic clasts.*

Figure 14. *The Latite Ridge Latite (Tlr) showing the dark reddish-brown, densely welded ignimbrite, abundant lithic inclusions and black flattened pumice lapilli. The largest mafic fiamme (black blebs) shown by black arrow is 6 inches (15 cm) long.*

Figure 15. *Hand sample of the tuff of Rattlesnake Pass member (Tpr) of the Packard Quartz Latite with abundant quartz phenocrysts that are characteristic of the unit.*

crysts of plagioclase, biotite, sanidine, quartz, and likely hornblende; also contains 0.4 to 1 inch (1–3 cm) lithic clasts of other igneous rocks; forms resistant ridges; mapped near the mouth of Tintic Davis Canyon; $^{40}Ar/^{39}Ar$ radiometric dating of the sanidine showed the unit to be 35.21 ± 0.03 Ma (table 2) (sample AR-1708; McKean, 2011; Christiansen and others, 2013); thickness 0 to 65 feet (0–20 m).

Tplt **Packard Quartz Latite, lava flow and tuff member** (upper Eocene) – Upper lava and vitrophyre and lower tuff breccia; the upper lava is a porphyritic, devitrified, lava flow unit with flow bands 0.4 to 2.4 inches (1–6 cm) thick, with phenocrysts of plagioclase, biotite, sanidine, and quartz; the lava has a black, glassy, basal vitrophyre, with flow foliations of 0.08 to 0.4 inches (1 mm to 1 cm) thick; the lower tuff breccia is a loosely welded white tuff with phenocrysts of plagioclase, biotite, and quartz in a glassy matrix; also contains large lithic volcanic clasts (4 to 20 inches [10–50 cm]) of subrounded breccia; mapped separately from the other two Packard Quartz Latite members because of the large lithic volcanic clasts; forms ledges and slopes in the southwestern corner of the quadrangle; lava member yielded an $^{40}Ar/^{39}Ar$ sanidine radiometric age of 35.25 ± 0.04 Ma (table 2) (Allen, 2012; Christiansen and others, 2013); the upper lava is 0 to 15 feet (0–5 m) thick, basal vitrophyre of the upper lava is 0 to 15 feet (0–5 m) thick, and the lower tuff breccia is 0 to 30 feet (0–10 m) thick.

Major unconformity

PALEOZOIC

PENNSYLVANIAN

IPobp **Oquirrh Group, Butterfield Peaks Formation** (Middle to Lower Pennsylvanian, Desmoinesian-uppermost Morrowan) – Interbedded limestone and calcareous sandstone intervals; limestone is light gray to medium gray and fossiliferous; limestone contains locally abundant brachiopod, bryozoan, coral, and fusulinid fauna; thinly bedded with characteristic black spherical chert 0.2 to 2 inches (0.5–5 cm) in diameter; to the northwest of the quadrangle in the Thorpe Hills, includes light-brown calcareous sandstone that is thin to medium bedded and locally cross-bedded and includes some poorly exposed light-gray siltstone and mudstone interbeds (Disbrow, 1957); overall limestone is more common than the calcareous sandstone; unit forms ledges and cliffs with regularly intervening slopes; Clark and others (2012) reported IPobp corresponds to Oquirrh Formation units 2 through 5 of Disbrow (1957); we follow Oquirrh nomenclature of Clark and others (2012); age from Morris and Lovering (1961), and Desmoinesian conodont age from Ten Mile Hill (sample AR-1908; S.M. Ritter, Brigham Young University, written communication, 2008); isolated knobs of the unit are exposed near the northwestern quadrangle boundary; upper and lower contacts are not exposed; estimated knob exposure 330 feet (100 m) thick; just northwest of quadrangle in the Thorpe Hills, Disbrow (1957) reported an incomplete thickness of about 3650 feet (1110 m), top not exposed; to north on Butterfield Peaks in Oquirrh Mountains, Tooker and Roberts (1970) reported a measured thickness of 9072 feet (2765 m).

Not in contact (see Biek and others, 2009, and Clark and others, 2012, for bedrock units not exposed in Allens Ranch quadrangle).

PENNSYLVANIAN-MISSISSIPPIAN

Mmc **Manning Canyon Formation** (Lower Pennsylvanian? to Upper Mississippian) – Mapped in Tenmile Pass area (Clark and others, 2012) but not exposed in the Allens Ranch quadrangle.

Tenmile Pass fault (Clark and others, 2012)

MISSISSIPPIAN

Great Blue Limestone – The Great Blue Limestone has a variety of formal and informal members mapped in nearby quadrangles and mountain ranges (see Disbrow; 1957, 1961; Morris and Lovering, 1961; Biek and others, 2009; Clark and others, 2012). Clark and others (2012) revised the extent of the Great Blue Limestone in the southern Oquirrh and northern East Tintic Mountains. They included strata previously mapped by Disbrow (1957, 1961) and Morris and Lovering (1961) as the Poker Knolls Limestone and Chiulos Shale Members of the Great Blue Limestone in the Manning Canyon Formation. From a location near Chiulos Canyon in the quadrangle (see sample AR-2 location on plate 2), a UGS shale-gas resources study identified Chesterian? palynomorphs in the Great Blue Limestone (Chidsey, 2016, appendix O). More biostratigraphic work is needed in the East Tintic Mountains to compare the poorly exposed Poker Knolls Limestone Member and Chiulos Shale Member with the Manning Canyon Formation (see Clark and others, 2012). We used the Disbrow (1957, 1961) and Morris and Lovering (1961) divisions of the Great Blue Limestone here in the structurally complex northern East Tintic Mountains of the Allens Ranch quadrangle. Morris and Lovering (1961) reported a combined thickness of about 2500 feet (760 m) for their four members of the Great Blue Limestone in the East Tintic Mountains.

Mgb **Great Blue Limestone, undivided** (Upper Mississippian) – Limestone, argillaceous limestone, silty limestone, and shale that are tectonically sheared; locally includes silicic jasperoid breccias too small to map separately; gray to maroonish-gray fossiliferous limestone and fossil hash beds; silty orange to pinkish stringers in argillaceous limestone; forms slopes to ledges; mapped on the northeastern boundary of the quadrangle where Great Blue Limestone members are indistinguishable at map scale due to tectonic deformation and alteration; age from Morris and Lovering (1961); estimated incomplete thickness greater than 650 feet (200+ m); Disbrow (1957, 1961) provided approximate total thickness of 2500 feet (330 m) in the Thorpe Hills and northern East Tintic Mountains for their undivided Great Blue Limestone; in the East Tintic Mountains Morris and Lovering (1961) reported a combined thickness of about 2500 feet (760 m) for their four members of the Great Blue Limestone.

Mgbk **Poker Knoll Limestone Member** (Upper Mississippian) – Thin- to medium-bedded, gray to tan limestone and dolomite, with some interbedded black shale and black chert; fossiliferous with corals and crinoids (Morris and Lovering, 1961); mapped only in the western part of Tintic Davis Canyon where it forms a slope; the lower contact is at the transition from black shales to drab shales, quartzite, and shaley limestones of the Chiulos Member; age from Morris and Lovering (1961); thickness is 590 to 705 feet (180–215 m); Morris and Lovering (1961) reported a thickness of 600 to 700 feet (183–213 m) feet on southeast side of Tenmile Pass, just northwest of quadrangle.

Mgbc **Chiulos Member** (Upper Mississippian) – Black, dark-brown and drab shales and shaley limestone; some interbedded brown to tan cross-bedded quartzite; lower portion of the unit is mostly thick-bedded shale with thin-bedded quartzite; upper half has more quartzite beds with interbedded shale and argillaceous limestone (Morris and Lovering, 1961); forms slopes mapped in the southwestern part of the quadrangle; the lower contact is at the transition from shales to interbedded limestone (nodular chert bearing) and shale of the Paymaster Member; age from Morris and Lovering (1961); 820 to 950 feet (250–290 m) thick; Morris and Lovering (1961) reported a thickness of 899 feet (274 m) from Chiulos Canyon and 850 feet (260 m) from the southwest side of Tenmile Pass.

Mgbp **Paymaster Member** (Upper Mississippian) – Gray to medium-gray limestone, with interbedded, brown-weathering, olive-green shale and sandstone; limestones are medium bedded, shales are thin bedded; argillaceous limestone commonly streaked with tan and red to maroon siltstone and claystone; nodules and thin-bedded red-brown chert common; locally contains fossils of crinoids, corals, bryozoans and brachiopods (Morris and Lovering, 1961); forms slopes mapped in the southwestern and northeastern parts of the quadrangle; the lower contact is at the first thick limestone bed of the Topliff Limestone Member; age from Morris and Lovering (1961); thickness is 590 to 660 feet (180–200 m); Morris and Lovering (1961) reported a thickness of 623 feet (190 m) from Edwards Canyon in the northern East Tintic Mountains.

Mgbt **Topliff Limestone Member** (Upper Mississippian) – Gray to medium-gray, fine- to medium-grained limestone; thin to thick bedded; locally fossiliferous with rugose corals, crinoids, bryozoans, brachiopods, and gastropods (Morris and Lovering, 1961); ledge former mapped in the southwestern and northeastern parts of the quadrangle; the lower contact is at the first thick sandstone bed of the Humbug Formation; age from Morris and Lovering (1961); thickness is 295 to 330 feet (90–100 m); Morris and Lovering (1961) reported a thickness of 462 feet (140 m) from Edwards Canyon and 300 feet (90 m) from Paymaster Hill in the East Tintic Mountains.

Mh **Humbug Formation** (Upper Mississippian) – Interbedded, calcareous, quartz sandstone and limestone; sandstone is light- to dark-brown, weathering pale yellowish brown to olive gray; medium to very thick bedded; weathers to ledgy slopes; locally dolomitic and locally contains crinoids, spiral gastropods, and fossil hash; limestone rarely contains dark-gray or white chert nodules; sandstone is fine to medium grained with well-sorted and rounded grains, and has low-angle cross-stratified, lenticular beds; lower contact with the Deseret Limestone (Md) is gradational and occurs at the change from alternating sandstone and limestone (Mh) to limestone (Md); age from Morris and Lovering (1961); thickness is 690 to 750 feet (210–230 m); in the Soldiers Pass quadrangle Biek and others (2009) reported a thickness of about 700 to 750 feet (210–230 m); in the East Tintic Mountains the reported thickness is 650 feet (200 m) (Morris and Lovering, 1979).

Md **Deseret Limestone** (Upper to Lower Mississippian) − Medium-dark-gray, variably sandy and fossiliferous limestone; subdivided into three parts for description but not for mapping purposes, parts correspond to the members mapped by Morris and Lovering (1961, 1979).

Upper part (Uncle Joe Member) is coarse-grained, thick-bedded limestone containing nodular chert and beds of fossilized coquina (shell hash); locally dolomitic; the hash is composed of fragments of broken shells, crinoid columns, and corals arranged into laminae and cross-beds; cross-beds have similar weathered appearance and can be confused with the sandstone beds of the Humbug Formation.

Middle part (Tetro Member) is a sequence of very thick bedded, medium- to light-blue-gray cherty limestone; the chert is mostly nodular with some beds 2 to 4 inches (5–10 cm) thick; most of the chert is dark gray to black in color, but some is white; fossils include rugose corals, crinoids, bryozoans, fossil hash, and uncommon brachiopods (Morris and Lover-ing, 1961).

Lower part (Delle Phosphatic Member) is black carbonaceous shale to shaly limestone that contains one or more layers of pelletal phosphorite; this part of the section is rarely well exposed on the surface and usually weathers to small shale chips of maroon gray to dull orange red (Morris and Lovering, 1961; Sandberg and Gutschick, 1984); shale locally contains cherty beds but not as extensive as the Gardison Limestone.

Forms slopes and ledges; lower contact is mapped above the bedded chert of the Gardison Limestone at the base of the Delle Phosphatic Member shaly slope; age from Morris and Lovering (1961) and Sandberg and Gutschick (1984); 660 to 820 feet (200–250 m) thick; in the Soldiers Pass quadrangle Biek and others (2009) reported a complete thickness of about 700 to 750 feet (210–230 m) in the Lake Mountains and about 1000 feet (300 m) in the Mosida Hills; in the East Tintic Mountains the reported thickness is 1000 to 1100 feet (300–340 m) (Morris and Lovering, 1961, 1979).

Mg, Mg?

Gardison Limestone (Lower Mississippian) – Medium-gray to dark-gray limestone including cherty limestone, fossiliferous limestone, and locally dolomitic limestone; medium- to very thick bedded; chert is present as black, irregularly shaped nodules and thin (1 to 6 inches [2–15 cm]) discontinuous beds; bedded chert is characteristic of the upper part of the unit, which is thicker bedded compared to the thinner bedded lower part; fossils include rugose and colonial corals, brachiopods, crinoids, distinctive gastropods, and bryozoans; contains minor intraformational flat-pebble conglomerate beds; ledge forming; queried in one location in the northeastern part of the quadrangle where unit is uncertain; the lower contact is distinguished by the characteristic "curly" bed limestone at the top of the Fitchville Formation (Proctor and Clark, 1956; Morris and Lovering, 1961); age from Morris and Lovering (1961); 500 to 660 feet (150–200 m) thick; 450 to 550 feet (140–170 m) thick in the Eureka quadrangle (Morris, 1964a); 500 feet (150 m) thick in East Tintic Mountains (Morris and Lovering, 1961).

Unconformity? (see Hintze and Kowallis [2009]; Greenhalgh [1980] did not suggest an unconformity here)

MISSISSIPPIAN-DEVONIAN

MDf **Fitchville Formation** (Lower Mississippian to Upper Devonian) – Light-gray to gray limestone and dolomite; medium to thick bedded; upper part is a mottled dark gray and brown dolomitic limestone; fossils include rugose and colonial corals, crinoids, brachiopods, and bryozoans; forms ledges; top of unit contains the "curly" bed limestone, a stromatolitic limestone a few inches to approximately 3 feet (1 m) thick (Proctor and Clark, 1956; Morris and Lovering, 1961; Greenhalgh, 1980); lower contact is marked at transition from light-gray limestone and dolomite of Fitchville to argillaceous limestone of Pinyon Peak Limestone; age from Morris and Lovering (1961), refined to Kinderhookian to Famennian age based on conodont zones and fossils, which show an unconformity within the unit between the Mississippian and Devonian strata (Greenhalgh, 1980); complete measured thickness is 330 to 500 feet (100–150 m); in the East Tintic Mountains the thickness is 280 to 300 feet (85–90 m) (Morris and Lovering, 1961, 1979).

DEVONIAN

Dp **Pinyon Peak Limestone** (Upper Devonian) – Limestone, medium- to light-blue-gray commonly with a faint pink color, fine-grained and thin- to medium-bedded, argillaceous, with few intraformational flat-pebble conglomerate beds; fossils include corals, brachiopods, and crinoids (Morris and Lovering, 1961); forms erosional slopes; lower contact placed above uppermost quartzite cross-beds or sandy dolomites of underlying Victoria Formation; age from Morris and Lovering (1961), and refined to Famennian age based on conodont zones (Early *expansa* Zone) (Stock and Sandberg, 2019); thickness is 100 to 330 feet (30–100 m), structurally thinned in some locations; 70 to 125 feet (20–40 m) thick in the East Tintic Mountains (Morris and Lovering, 1979).

Dv **Victoria Formation** (Upper Devonian) – Gray dolomite interlayered with medium-grained, light-brown, thin- to medium-bedded, rusty-weathering quartzite; dolomite is fine- to medium-grained, commonly with clumps of dolomite crystals up to 0.4 inch (1 cm) in diameter; quartzite beds are typically more resistant than surrounding dolomite; forms ledges where the quartzite is exposed; lower contact is placed below the base of the lowest prominent quartzite bed; a Late Devonian age is assigned based on the age of the underlying Bluebell Dolomite and overlying Pinyon Peak Limestone (Morris and Lovering, 1961); thickness is 300 feet (90 m); in the East Tintic Mountains the thickness is 250 to 300 feet (75–90 m) (Morris and Lovering, 1979).

Unconformity (Stansbury uplift, Rigby, 1959; Rigby and Clark, 1962; Morris and Lovering, 1961; Tooker, 1999)

DEVONIAN-SILURIAN-ORDOVICIAN

DOb **Bluebell Dolomite** (Lower Devonian to Upper Ordovician) – Dark-gray and blue-gray dolomite; thinly bedded with stromatolites and some brown chert stringers; cherty near the base and more sandy near the top; forms ledges; lower contact is placed at the base of the light-gray-weathering, thin-bedded, fine-grained dolomite unit, directly overlies the Fish Haven Dolomite "Leopard Skin" marker bed; age range from Early Devonian to Late Ordovician (Morris and Lovering, 1961), likely contains one or more internal disconformities (Morris and Lovering, 1961); thickness is 330 to 500 feet (100–150 m); in the East Tintic Mountains the thickness is 335 to 600 feet (100–185 m) (Morris and Lovering, 1979).

ORDOVICIAN

Ofh **Fish Haven Dolomite** (Upper Ordovician) – Light- to medium-gray mottled limestone; nodular black chert near the base; medium to thick bedded; fossils include crinoids, bryozoans, brachiopods, gastropods, and corals; thicker medium-gray beds are mottled with irregular cream-colored spots an inch (2.5 cm) or more in diameter; "Leopard Skin" marker bed at the top of the unit is a ledge-forming dolomite unit that is medium to dark-gray, mottled, with irregular light- to medium-gray patches of coarser-grained dolomite (Morris and Lovering, 1961); lower contact mapped at the appearance of the argillaceous Opohonga Limestone; age from Morris and Lovering (1961); thickness is 330 to 500 feet (100–150 m); in the East Tintic Mountains the thickness is 200 to 345 feet (60–105 m) (Morris and Lovering, 1979).

Unconformity (Tooele arch, Hintze, 1959; Morris and Lovering, 1961, and references therein; and Ethington and others, 2016)

Oo **Opohonga Limestone** (Lower Ordovician) – Light-blue-gray to light-brown limestone and argillaceous limestone that is thin to medium bedded; weathered lenses and bands of light-blue-gray limestone alternating with seams and beds of pinkish-red and yellow silty and argillaceous limestone give it a striped, mottled, or mosaic appearance (Morris and Lovering, 1961); contains intraformational flat-pebble conglomerates; the whole section is rarely well exposed and typically weathers to a slope composed of pinkish-red, orange-red, and yellow sandy chips; the lower contact is placed at the appearance of argillaceous limestone beds above the cherty dolomite beds of the Ajax Dolomite; age from Morris and Lovering (1961) and Ethington and others (2016); thickness is 500 to 1000 feet (150–300 m); in the East Tintic Mountains the thickness is 300 to 850 feet (90–260 m) (Morris and Lovering, 1961, 1979).

CAMBRIAN

Ꞓa **Ajax Dolomite, undivided** (Upper Cambrian) – Light-gray to dark-gray cherty dolomite; subdivided into three members including the upper member, Emerald Member, and lower member by Morris and Lovering (1961, and references therein); mapped in one location south of mouth of Pinyon Canyon; Late Cambrian age based on fossils (Morris and Lovering, 1961), Ordovician-Cambrian boundary is debated in this part of Utah (see Hintze and Kowallis, 2009); in the East Tintic Mountains the combined thickness is 560 to 650 feet (170–200 m) (Morris and Lovering, 1961, 1979).

Ꞓau **Ajax Dolomite, upper member** (Upper Cambrian) – Dark bluish-gray dolomite, well-bedded, fine-grained, with white, brown, and black chert lenses; chert ranges from thin seams to discontinuous beds several inches thick and several feet long; ledge former; mapped in the Selma Hills and in one location northeast of Rattlesnake Pass (see plate 1, section 26, T. 8 S., R. 2 W., SLBLM); lower contact marked by change to distinctive gray-white dolomite of the Emerald Member; Late Cambrian age based on fossils (Morris and Lovering, 1961), Ordovician-Cambrian boundary is debated in this part of Utah (see Hintze and Kowallis, 2009); thickness is 300 to 330 feet (90–100 m); in the East Tintic Mountains the member ranges between 350 and 520 feet (106–160 m) thick (Morris and Lovering, 1961).

Ꞓae **Ajax Dolomite, Emerald Member** (Upper Cambrian) – Light gray-white dolomite, medium bedded; the middle bed of the unit has a characteristic light gray-white color that weathers to a mottled surface; ledge former; mapped in the Selma Hills; Emerald Member distinctively crops out between the two darker gray dolomite intervals of the upper and lower members (Morris and Lovering, 1961); age from Morris and Lovering, 1961); thickness is 30 feet (10 m); in the East Tintic Mountains the member averages 30 feet (10 m) thick (Morris and Lovering, 1961).

€al **Ajax Dolomite, lower member** (Upper Cambrian) – Light- to dark-gray cherty dolomite, medium to thin-bedded; beds contain small pods of black, brown, and white chert (fewer than upper member); some lighter colored dolomite beds are mottled or striped with layers of gray-blue dolomite; several of the beds are cross-bedded and a few are conglomeratic (Morris and Lovering, 1961); ledge former; mapped in the Selma Hills; lower contact at the transition from dolomite to the interbedded dolomite, shale, and sandstone of the Opex Formation; age from Morris and Lovering (1961); thickness is 130 to 160 feet (40–50 m); in the East Tintic Mountains the member averages 180 feet (55 m) thick (Morris and Lovering, 1961).

€o **Opex Formation** (Upper Cambrian) – Light grayish-blue, thin-bedded dolomite with some interbedded shale and sandstone; contains some sandy dolomite, pisolites, oolites, intraformational flat-pebble conglomerate, and some cross-bedded fossil hash (Morris and Lovering, 1961); unit forms slopes; lower contact placed above the alternating series of thinly laminated beds of lighter and darker gray dolomite of the Cole Canyon Dolomite; age from Morris and Lovering (1961); thickness is 260 to 300 feet (80–90 m); in the East Tintic Mountains the thickness is 143 to 245 feet (45–75 m) (Morris and Lovering, 1961).

€c **Cole Canyon Dolomite** (Upper to Middle Cambrian) – Alternating light-gray, blue-gray to dark-gray dolomite that is fine to medium grained; beds range from thinly laminated to thick and very thick; locally mottled and with flat-pebble conglomerate and dark-gray chert nodules near the top of the formation (Morris and Lovering, 1961); typically darker beds are mottled and lighter beds are finely laminated, some beds have wavy laminations and a light-gray color; a few units contain small twig-shaped rods of calcite and dolomite that previous mappers called “twiggy bodies” (Madsen, 1952); forms ledges; lower contact not exposed in quadrangle; age from Morris and Lovering (1961); entire unit not exposed in quadrangle, estimated exposed thickness greater than 330 feet (100 m); 830 to 900 feet (255–275 m) thick in the East Tintic Mountains (Morris and Lovering, 1979).

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