

# Geologic Map of the Southern Fish Creek Range, Eureka and Nye Counties, Nevada

by

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## INTRODUCTION

The southern part of the Fish Creek Range is located in central Nevada, ~40 km south of the town of Eureka (fig. 1). Previous studies in the Fish Creek Range (e.g., Merriam, 1967; Hose, 1983; Sans, 1986) have presented differing interpretations of the tectonic significance of Paleozoic, Mesozoic, and Cenozoic rock units exposed in the southern part of the range, including using different naming schemes for Paleozoic sedimentary rock units (e.g., Hose, 1983; Poole et al., 1983) and varying interpretations of the depositional age range and nature (i.e., stratigraphic versus structural) of the upper and lower contacts of the Cretaceous Newark Canyon Formation (NCF) and Paleogene Sheep Pass Formation (e.g., Hose, 1983; Sans, 1986). These Cretaceous and Paleogene sedimentary units are only sparsely exposed in eastern Nevada, and therefore the southern Fish Creek Range is an important field locality that offers a rare opportunity to bracket the timing of Mesozoic and early Cenozoic depositional events. In addition, the southern Fish Creek Range also has been interpreted to lie within the central Nevada thrust belt (CNTB), a system of north-striking, east-vergent thrust faults and folds that branch northward off the Sevier thrust in southern Nevada (fig. 1; e.g., Taylor et al., 1993, 2000). However, to date there have been vastly differing interpretations presented for the geometry, timing, and tectonic significance of contractional structures in the southern Fish Creek Range (e.g., Hose, 1983; Sans, 1986).

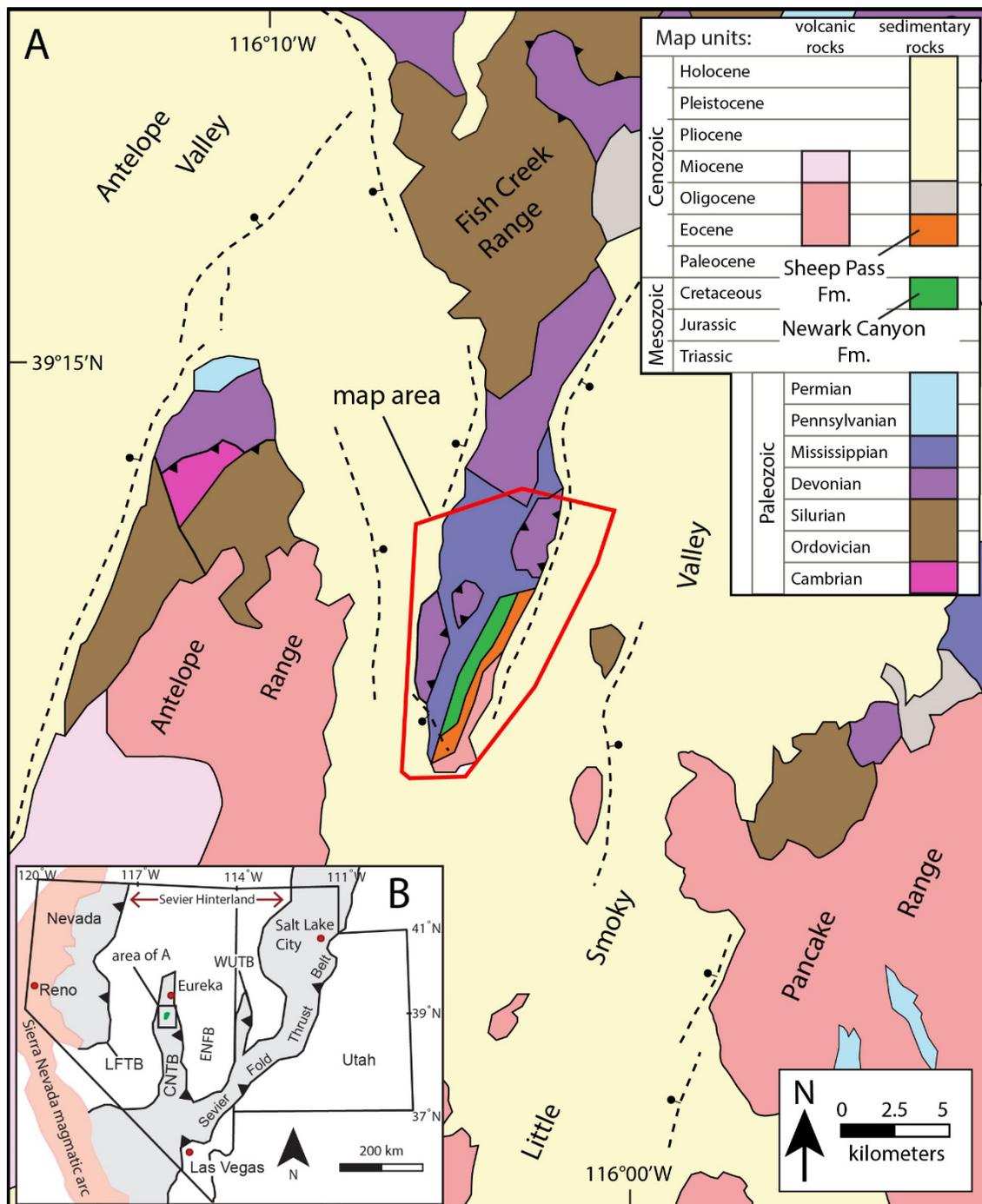
The purpose of this study is to present an updated structural and stratigraphic interpretation of rock units in the southern Fish Creek Range. Here, we present a new 1:15,000-scale geologic map, which covers an area of ~21.5 km<sup>2</sup> and focuses on the outcrop extent of the NCF and Sheep Pass Formation. This technical report, which is meant to accompany the geologic map, presents revisions to the

Paleozoic stratigraphy as mapped by Hose (1983), divides the NCF into four mappable members, and presents an updated view of the structural framework of the range, including documenting a previously unmapped thrust fault. In addition, new U-Pb zircon geochronology presented in Di Fiori et al. (2021) provides additional depositional age constraints on both the NCF and the Sheep Pass Formation.

## STRATIGRAPHY

Bedrock units exposed in the map area consist of Late Devonian to Mississippian carbonate and clastic rocks, Early Cretaceous fluvio-lacustrine clastic sedimentary rocks of the NCF, late Eocene to early Oligocene alluvial sediments of the Sheep Pass Formation, and late Eocene and early Oligocene felsic volcanic rocks. The Late Devonian rock units represent the upper part of the Neoproterozoic-Devonian Cordilleran passive margin basin section (e.g., Stewart and Poole, 1974; Stewart, 1980). Mississippian rocks in the map area are represented by the Diamond Peak Formation, which is interpreted to have been deposited in a foreland basin that subsided to the east of the highlands formed during the Antler orogeny (e.g., Speed and Sleep, 1982; Poole et al., 1992). In the map area, the Diamond Peak Formation contains several lithologies, but mainly consists of medium- to coarse-grained sandstone rich in chert clasts, with lesser abundances of pebble to cobble, chert-clast conglomerate (which supports a prominent N-trending ridge in the center of the map area), limestone, shale, and siltstone.

The only Mesozoic rock unit in the map area is the NCF, which consists of an upward-fining sequence of conglomerate, sandstone, mudstone, and lacustrine carbonate (e.g., Hose, 1983; Vandervoort, 1987), which overlies the Mississippian Diamond Peak Formation across an angular unconformity with ~10–20° of dip difference. We have divided the NCF into four members. Knc<sub>1</sub>, the basal



**Figure 1.** A) Geologic map of part of east-central Nevada (simplified from Crafford, 2007), showing the location of the map area and the names of surrounding ranges and valleys. Locations of Quaternary faults are from the USGS fault and fold database (2006). B) Inset map (modified from Long et al., 2014a) showing the spatial extents of Cordilleran thrust systems of Nevada and Utah (shaded light gray) and the Sierra Nevada magmatic arc (shaded red). The Newark Canyon Formation exposure in the southern Fish Creek Range is shown in green. Abbreviations: CNTB = central Nevada thrust belt; ENFB = eastern Nevada fold belt; LFTB = Luning-Fencemaker thrust belt; WUTB = western Utah thrust belt.

member, is dominated by cross-bedded pebble conglomerate and sandstone. Knc<sub>2</sub> consists of well-bedded, cross-bedded sandstone with massive pebble conglomerate lenses. Knc<sub>3</sub> is dominated by weakly indurated fossiliferous mudstone with intercalated fine-grained carbonate beds. Knc<sub>4</sub> consists of white to cream-colored, well-bedded micrite. The NCF in the southern Fish Creek Range has been previously interpreted to have been deposited during the Early Cretaceous (Barremian to Albian) based on fossils including ostracods, charophytes, and palynomorphs documented by Fouch, et al. (1979). Later work by Carpenter et al. (1993) yielded a single apatite fission-track age of  $116 \pm 13$  Ma (Aptian) from an NCF outcrop along Cockalorum Wash in the southern Fish Creek Range. We interpret this as a maximum depositional age, which represents the timing of erosion within the source area, prior to deposition of the NCF. Bonde et al. (2015) documented iguanodontia and oviraptor dinosaur fossils from NCF member Knc<sub>3</sub> in the southern Fish Creek Range, which defines an Aptian or younger deposition age. Finally, U-Pb detrital zircon ages (Di Fiori et al., 2021) yielded a maximum deposition age (as defined by the weighted mean age of the five youngest grains that overlap within error) of  $130.6 \pm 2.6$  Ma for the basal member of the NCF in the map area (Knc<sub>1</sub>), indicating that the NCF in the southern Fish Creek Range was deposited no earlier than the Hauterivian stage. In summary, available geochronologic data and fossil assemblages indicate that deposition of the NCF in the southern Fish Creek Range can be bracketed between the Hauterivian (~133 Ma) and the Albian (~100 Ma) (Fouch et al., 1979; Carpenter et al., 1993; Bonde et al., 2015; Di Fiori et al., 2021).

Paleogene rocks in the map area include late Eocene to Oligocene sedimentary rocks and rhyolitic ash-flow tuffs and lavas. The Sheep Pass Formation (Tsp), which consists of massive cobble conglomerate, overlies the NCF across an angular unconformity with up to ~30° of difference in dip. A previous age interpretation based on lithologic comparison (Fouch et al., 1979) estimated the age of the Sheep Pass Formation in the southern Fish Creek Range to be Maastrichtian–Paleocene. U-Pb detrital zircon ages from a sample of the Sheep Pass Formation in the map area (Di Fiori et al., 2021) yielded a weighted mean age of  $33.7 \pm 0.6$  Ma (defined by the youngest 5 grains that overlap within error), defining a late Eocene to early Oligocene maximum depositional age. Volcanic units in the map area include silicic ash flow tuffs and lavas. The oldest dated volcanic unit is a late Eocene rhyodacite (Tr) in the northeastern part of the map area, which has an emplacement age of  $34.4 \pm 0.8$  Ma (K-Ar of sanidine; personal communication by E.H. McKee in Hose, 1983). This rhyodacite does not exhibit field relationships with the Sheep Pass Formation. To the south, the Oligocene Windous Butte Formation (Twb), a rhyolitic ash-flow tuff with an emplacement age of  $32.5 \pm 0.8$  to  $32.3 \pm 1.0$  Ma (K-Ar of sanidine; personal communication by E.H. McKee in Hose, 1983), conformably overlies the Sheep Pass Formation. This field relationship brackets the upper age for deposition of the

Sheep Pass Formation at ~32.5 Ma. In the southeastern corner of the map area, an undated lava flow unit named the hypersthene rhyodacite (Thr) (Hose, 1983) conformably overlies the Windous Butte Formation, and is locally interlayered with agglomerate (Hose, 1983).

Neogene units in the map area include lacustrine sediments and landslide megabreccias. Tuffaceous lake sediments (unit Ts), which contain minor amounts of intercalated freshwater limestone and ash-fall tuff, dominate exposures in the western portion of the map area. The exact age of unit Ts is uncertain, but a lack of tilting likely indicates that these lake sediments are Neogene (Hose, 1983). Four isolated exposures of brecciated, coarse-crystalline carbonates (unit Tbx) are present on the eastern flank of the range. We interpret these as megabreccia landslide blocks that were most likely sourced from outcrops of Devonian carbonates on the western side of the range. These landslide megabreccia blocks overlie Paleogene units as young as the early Oligocene Windous Butte Formation and post-date the eastward tilting of Eocene–Oligocene rocks. Because of this field relationship, we interpret that emplacement of these slide blocks likely occurred during the Neogene.

Quaternary deposits in the map area include alluvial stream channels and associated terraces, hillslope-covering colluvium, and multiple generations of alluvial-fan deposits. Active alluvial-fan deposits (Qaf) cover most of the eastern half of the map area. A single older, topographically elevated alluvial-fan deposit (Qoaf) was observed in the east-central part of the map area. The youngest Quaternary surficial deposits include hillside colluvium (Qc) and modern-day alluvium within active washes (Qal) and terraces (Qalt).

## STRUCTURAL FRAMEWORK

Bedrock and surficial deposits in the southern Fish Creek Range record multiple episodes of deformation. Contractural structures in the map area include multiple traces of N-striking, shallowly W-dipping (~10–25°), top-to-E thrust faults that place Devonian carbonates (units Ddg, Dox, and Dbp) over Mississippian clastic rocks (unit Mdp). We interpret that these thrust traces represent isolated, preserved exposures of the same through-going thrust fault, which is here named the Vanadium thrust, after historical vanadium prospects near the range. This thrust fault deforms rocks as young as unit Mdp. In the footwall of the Vanadium thrust, unit Mdp dips moderately eastward in most places. However, in the north-central part of the map, unit Mdp is folded into a N- to NNW-trending anticline, the hingeline of which can be traced for a map distance of ~2 km.

Though field relationships between the Vanadium thrust and Mesozoic rock units are not exposed, we consider it likely that the thrust is genetically related to thrust faults of the central Nevada thrust belt (CNTB), which are exposed in the surrounding region. This interpretation is supported by observations of several other north-striking, east-vergent thrust faults along-strike to the north in the Fish Creek Range

and Diamond Mountains, to the west in the Antelope Range, and to the east in the Pancake Range, which have been interpreted to be part of the Cordilleran (i.e., late Mesozoic) CNTB (e.g., Hose, 1983; McDonald, 1989; Carpenter et al., 1993; Nolan et al., 1974; Taylor et al., 1993, 2000; Long, 2012, 2015; Long et al., 2014a; Di Fiori et al., 2020, 2021). Approximately ~35 km along-strike to the north in the Diamond Mountains, field relationships between the Early Cretaceous NCF and several thrust faults and folds demonstrate that the NCF was deposited and deformed during CNTB deformation (Long et al., 2014a; Di Fiori et al., 2020). Though the field relationships necessary to evaluate this are not exposed in our map area, we consider it likely that motion on the Vanadium thrust formed a highland to the west while the footwall to east subsided, and that the NCF was deposited within the accommodation generated in its footwall. This interpretation is supported by clast composition data from the NCF, which are rich in dolomite clasts that were most likely sourced from Devonian carbonate units in the hanging wall of the Vanadium thrust. Additionally, Vandervoort (1987) measured pebble clast imbrication and cross bed trough orientations, which defined an east-southeast (~106° average azimuth) paleocurrent direction for the NCF. If this interpretation is correct, then NCF deposition was genetically related to motion on the Vanadium thrust, and thus provides another example, in addition to the case study of the NCF in the Diamond Mountains (Di Fiori et al., 2020), that CNTB deformation at this latitude took place during the Early Cretaceous.

The NCF has been tilted eastward and exhibits variable dip magnitudes along strike, including up to 70–80° dips preserved in the northern part of the exposure, dips up to ~50° near the southern end of the range, and average dips of ~30° in between. Late Eocene-Oligocene rocks on the eastern flank of the range exhibit consistent 25–30° average eastern dips. After retro-deforming this younger tilting, this indicates that the NCF was locally dipping as steeply as 20–50° eastward prior to the late Eocene. We interpret that tilting of the NCF was most likely the result of Early Cretaceous folding associated with regional contractional deformation within the CNTB (e.g., Taylor et al., 1993, 2000; Long, 2012, 2015; Long et al., 2014a; Di Fiori et al., 2020). The eastward paleo-dips of the NCF imply that a syncline hingeline may be concealed under Little Smoky Valley to the east. This is compatible with the traces of multiple folds that have been revealed through mapping and construction of subcrop maps in the Pancake Range to the east (e.g., Kleinhampl and Ziony, 1985; McDonald, 1989; Perry and Dixon, 1993) and the northern Fish Creek Range and Diamond Mountains to the northeast (e.g., Nolan et al., 1971, 1974; Long, 2012, 2015; Long et al., 2014a; Di Fiori et al., 2020).

The late Eocene to early Oligocene Sheep Pass Formation (Tsp) overlies the NCF in the map area across an angular unconformity with up to ~20–50° of difference in dip. We interpret that the ~25–30° eastward dip of unit Tsp and overlying Oligocene volcanic rocks is most likely the result of tilting accommodated by regional, Neogene Basin

and Range normal faulting. Several N-striking normal faults with meter-scale displacement that offset the NCF are present in the central part of the map area. In addition, two Quaternary normal faults lie within the map area (Koehler and Wesnousky, 2011). These include a NNE-striking, down-to-the-east normal fault on the eastern flank of the range and a NW-striking, down-to-the-west normal fault to the southwest of the southern tip of the range. Both Quaternary faults are concealed beneath recent alluvial deposits and their offset magnitudes are not known.

#### **A note on previous structural and stratigraphic interpretations in the map**

In an effort to maintain continuity of stratigraphic nomenclature across this region of central Nevada, we have chosen to use different unit names for several Paleozoic map units than used by Hose (1983). Most significantly, we have interpreted clastic rocks mapped by Hose (1983) as the Mississippian Antelope Range Formation (his units Mar and Marc) and the Devonian Webb Formation (his unit Dw) as the Mississippian Diamond Peak Formation (our unit Mdp). This is consistent with the more regionally accepted stratigraphic nomenclature used farther to the north in the Fish Creek Range and Diamond Mountain (e.g., Nolan et al., 1956; 1971; 1974; Long et al., 2014a, 2014b; Di Fiori et al., 2020) and is supported by lithologic similarity between these clastic rocks in the southern Fish Creek Range and the Diamond Peak Formation mapped ~20–30 km to the north in the northern Fish Creek Range (Nolan et al., 1956; 1974; Long et al., 2014a, 2014b). There, as well as in our map area, the Diamond Peak Formation is lithologically heterogeneous, containing interlayered conglomerate, sandstone, mudstone, and limestone.

In the southern Fish Creek Range, Hose (1983) also mapped multiple thrust faults that translate thin sheets of several different Devonian and Mississippian map units eastward (his units Dbp, Dox, Ddg, Dp, Dw, and Mw). We agree that there are older-over-younger thrust relationships in the map area, but we interpret a much simpler structural scenario, in which Devonian units Dpb, Dox, and Ddg have been emplaced eastward over Mississippian clastic rocks (unit Mdp) above what was likely a single, east-vergent thrust fault (our Vanadium thrust).

Multiple isolated landslide megabreccia outcrops (unit Tbx) are present on the eastern side of the map area, and overlie units Knc<sub>4</sub>, Tsp, and Twb. These outcrops consist of pervasively brecciated, coarse-crystalline limestone, which was likely derived from Devonian carbonate units. Hose (1983) originally mapped the basal contacts of these brecciated outcrops as thrust faults. Later, Sans (1986) interpreted that these isolated exposures of brecciated Devonian carbonates represent gravity slide blocks that were detached from the Roberts Mountain allochthon farther to the west, which slid eastward during the late Paleozoic. In contrast, we document that these exposures of brecciated carbonates overlie units Knc<sub>4</sub>, Tsp, and Twb, which requires a much younger emplacement age. We interpret these

outcrops as remnants of landslide blocks that were most likely detached from outcrops of Devonian carbonates in the western part of the map area, and we interpret that they most likely slid eastward during the Neogene, due to their angular relationship with underlying rocks that are as young as Oligocene.

## GEOLOGIC HISTORY

The southern Fish Creek Range exposes rock units that record depositional and deformation events that span from the Devonian to the present. Between the Neoproterozoic and Devonian, Nevada occupied a passive margin setting, and accumulated a thick section of shallow marine clastic and carbonate sediments (e.g., Stewart, 1980; Poole et al., 1992). In the map area, the top of this passive margin section is represented by several Devonian carbonate units (Dbp, Dox, and Ddg). During the Mississippian, deep marine slope and basinal sediments and volcanics in western Nevada were thrust eastward over shallow marine shelf carbonate and clastic sediments in central Nevada during the Antler orogeny (Speed and Sleep, 1982; Poole et al., 1992). Deformation associated with the Antler orogeny occurred within a few tens of km to the west of the map area (Stewart, 1980). During the Antler orogeny, clastic sediments were shed to the east and deposited in a foreland basin in eastern Nevada (Dickinson, 2004). In the map area, the Mississippian Diamond Peak Formation (Mdp) represents the sedimentary record of this foreland basin deposition. Following the Antler orogeny, eastern Nevada again experienced shallow marine deposition until the Triassic (e.g., Stewart, 1980). Though not exposed in the southern Fish Creek Range, several exposures of Pennsylvanian-Permian carbonate and clastic units in surrounding ranges record this depositional event (e.g., Nolan et al., 1974; Kleinhampl and Ziony, 1985).

During the Jurassic, the onset of Andean-style subduction outboard of Nevada initiated construction of the Jurassic-Paleogene North American Cordilleran orogenic belt (e.g., Allmendinger, 1992; Burchfiel et al., 1992; DeCelles, 2004; Yonkee and Weil, 2015). At the latitude of the map area, Nevada and westernmost Utah occupied a broad retroarc region between the Sierra Nevada magmatic arc and the frontal Sevier fold-thrust belt (fig. 1), commonly referred to as the ‘Sevier hinterland’ (e.g., Armstrong, 1972). Much of the hinterland was characterized by relatively minimal contractional deformation, including low-offset thrust faults and low-amplitude, long-wavelength folds (e.g., Gans and Miller, 1983; Taylor et al., 2000; Long, 2012, 2015). The map area has been interpreted to lie within the CNTB, a belt of N-striking, dominantly east-vergent thrust faults and folds that branches northward off of the Sevier fold-thrust front in southern Nevada (fig. 1; e.g. Taylor et al., 2000; Long et al., 2014a; Di Fiori et al., 2020, 2021). Based on the youngest rocks deformed by CNTB thrust faults and folds, combined with crosscutting relationships between CNTB structures and granitic intrusions, contractional deformation in many areas of the

CNTB can be bracketed between the Permian and the Late Cretaceous (Taylor et al., 2000).

The exposure of the NCF helps temporally constrain the timing of CNTB deformation at the latitude of the map area. Deposition of the NCF can be bracketed between ~133 Ma (a maximum depositional age obtained from U-Pb detrital zircon dating of the basal NCF member; Di Fiori et al., 2021) and ~100 Ma (the end of the Albian, which represents the youngest age range of fossils described within the NCF in the map area; Fouch et al., 1979; Bonde et al., 2015). Clast composition data support the interpretation that NCF deposition was genetically related to east-vergent motion on the Vanadium thrust, which is exposed in the western part of the map area. In addition, the NCF was tilted up to ~20–50° eastward prior to the late Eocene, which may be related to the construction of a proximal CNTB syncline.

The Sheep Pass Formation is exposed in multiple ranges in eastern Nevada, including the Egan, Grant and Pancake ranges (e.g. Winfrey, 1960; Kellogg, 1963; Fouch et al., 1979). Other researchers have interpreted the depositional setting of the Sheep Pass Formation as basin fill within active extensional half-grabens (e.g. Winfrey, 1960; Vandervoort and Schmitt, 1990; Druschke et al., 2009, 2011). In the map area, we obtained a maximum depositional age of ~34 Ma from the basal conglomerate of the Sheep Pass Formation using U-Pb dating of detrital zircons (Di Fiori et al., 2021). This, combined with the ~32 Ma age of overlying volcanic rocks, narrows the depositional age range for the Sheep Pass Formation to late Eocene-early Oligocene, which improves upon the Maastrichtian-Eocene speculated depositional age range of this unit from previous work (e.g., Fouch et al., 1979; Hose, 1983; Sans, 1986). The large clast size (cobble to boulder) of the Tsp conglomerate, combined with the dominant carbonate lithology of cobble clasts, implies proximal-to-source deposition. However, because of the absence of high-angle normal faults in the map area, genetically linking the deposition of the Sheep Pass Formation in the southern Fish Creek Range to early extension (e.g., Winfrey, 1960; Vandervoort and Schmitt, 1990; Druschke et al., 2009) is difficult. Instead, we note that the Sheep Pass Formation is tilted eastward by the same amount as overlying early Oligocene volcanic rocks, and therefore that this tilting is most likely associated with younger (i.e., post-depositional) regional normal faulting.

During the late Eocene and Oligocene, silicic volcanism swept from northeast to southwest across Nevada during the Great Basin ignimbrite flareup, which is interpreted as the result of rollback of the subducting Farallon plate following the Laramide orogeny (e.g., Humphreys, 1995; Smith et al., 2014). Volcanic rocks from this event are preserved in the map area and are represented by rhyolitic and rhyodacitic ash-flow tuffs and lavas. Most of these volcanic units have been dated between ~35 and ~32 Ma by previous workers (E.H. McKee personal communication in Hose, 1983; Hose, 1983).

From the middle Miocene to the present, the upper-crustal extension that has constructed the Basin and Range

Province has been pervasive throughout Nevada and has been attributed to the demise of subduction of the Farallon plate and the development of a transform boundary along the western North American plate margin (e.g., Atwater, 1970; Dickinson, 2006). The map area and the surrounding region show evidence of this extension in the form of multiple sets of generally N-striking normal faults (e.g., Stewart and Carlson, 1978). In the map area, range-bounding faults have been interpreted within Quaternary alluvial deposits on the eastern and western sides of the southern Fish Creek Range (Koehler and Wesnousky, 2011). We interpret that the ~25–30° eastward tilt magnitude recorded by late Eocene-Oligocene sedimentary and volcanic rocks on the eastern half of the map area is most likely the result of rotation accompanying Neogene Basin and Range normal faulting.

## DESCRIPTION OF MAP UNITS

### Quaternary Deposits

**Qx Artificial fill (Holocene)** Artificial fill; dump site.

**Qal Alluvium (Holocene)** Poorly sorted alluvial sediments with grain sizes ranging from mud to boulders. Deposited in active, ephemeral stream channels and washes.

**Qc Colluvium (Holocene)** Thin sediment veneer consisting of poorly sorted, angular deposits that cover steep hillsides and slopes. Clasts range in size from silt to boulders. Commonly found below ledge- and ridge-forming outcrops.

**Qalt Alluvial terrace deposits (Holocene)** Unconsolidated, poorly sorted alluvial sediments, ranging in size from silt to boulders. These sediments are incised by active washes and ephemeral stream channels.

#### *Alluvial-fan deposits*

**Qaf Young alluvial-fan deposits (Holocene)** Non-lithified silt and sand with less abundant pebbles and cobbles, deposited in active alluvial-fan systems. Exhibits poorly developed desert pavement, armoring, and incipient development of desert varnish at surface.

**Qoaf Inactive alluvial-fan deposits (Holocene to Pleistocene)** Abandoned alluvial-fan deposits composed of unlithified clasts between silt to boulder size. Exhibits moderately developed desert pavement and armoring compared to Qaf. Limited to a single exposure in the east-central part of the map.

### Cenozoic Rocks

**Tbx Landslide megabreccia deposits (Miocene?)** Brecciated exposures of gray, coarse-crystalline limestone on the east side of the map area. Outcrops are ledge forming

and some preserve original bedding. Overlie Cretaceous (Knc) and late Eocene-early Oligocene (Tsp, Twb) rocks. Interpreted as landslide blocks sourced from Devonian outcrops to the west.

**Ts Tuffaceous lake sediments (Miocene)** Pale-yellow to buff, weakly consolidated tuffaceous lacustrine deposits. Consist of interlayered light-gray, glass shard and lithic-bearing tuff, volcanoclastic pebble conglomerate and medium- to coarse-grained sandstone, and less abundant thin-bedded, white to yellow-brown micrite. Forms subdued topography and is most commonly exposed in the walls of active washes. ~100 meters minimum thickness.

**Thr Hypersthene rhyodacite (Oligocene)** Dark brown, dark gray, to black rhyodacite lava and agglomerate with yellow to white pumice breccia tuff at the base. Contains ~25% phenocrysts of potassium feldspar and hypersthene within in a dark, glassy groundmass. ~130 meters minimum thickness.

**Twb Windous Butte Formation (early Oligocene)** Black, red, pink, pale-yellow, or white rhyolitic ash-flow tuff. Exhibits ~40% phenocrysts, with abundant potassium feldspar and accessory biotite. Strongly welded horizons are common and often exhibit varying degrees of devitrification. Exposures in the southern part of the map area exhibit a clastic basal horizon consisting primarily of medium- to coarse-grained sandstone and siltstone, which contains angular, decameter-scale boulders of Paleozoic carbonate. Emplacement ages of  $32.5 \pm 0.8$  and of  $32.3 \pm 1.0$  Ma were determined from K-Ar of sanidine (E.H. McKee personal communication in Hose, 1983). ~80 meters thickness.

**Tsp Sheep Pass Formation (late Eocene to early Oligocene)** Tan, orange, and yellow, massive to crudely bedded, clast-supported conglomerate with sub-rounded to rounded clasts. Dominated by gray, pebble to cobble sized, coarse-crystalline, sub-rounded to rounded Paleozoic carbonate clasts. Thin, interstitial horizons of normally graded silty sandstone are locally present. Forms rounded hilltops and ledges. U-Pb geochronology from detrital zircons yielded a maximum depositional age of  $33.7 \pm 0.6$  Ma (Di Fiori et al., 2021). Overlying Windous Butte Formation brackets Tsp deposition age between ~33.7 and ~32.5 Ma. Exhibits a sharp, angular contact with the underlying Newark Canyon Formation. ~130 meters thick.

**Tr Rhyodacite (late Eocene)** Light brown to gray, locally red weathering, intermediate lava. Exhibits 15% plagioclase phenocrysts that have undergone varying degrees of alteration. Local cm-scale lensoidal horizons of white lithic tuff and pumice-breccia are present. Forms rounded, gentle slopes and ledges, which erode as small blocks. An emplacement age of  $34.4 \pm 0.8$  Ma was determined from K-Ar of sanidine (E.H. McKee personal

communication in Hose, 1983). ~120 meters minimum thickness.

## Cretaceous Rocks

### Knc Newark Canyon Formation

**Knc<sub>4</sub> Newark Canyon Formation member 4 (Early Cretaceous)** White, cream-colored, tan and buff, silty, massive, well-bedded micrite. Interstitial light brown, gray, and buff, fine-grained sandstone to mudstone is also abundant. Mudstone and fine-grained sandstone weather as flakes and thin plates, while the carbonate intervals weather as small blocks. Forms subdued topography and low-lying areas with low-relief, thin, weather-resistant strike-parallel fins. At least ~190 meters thick.

**Knc<sub>3</sub> Newark Canyon Formation member 3 (Early Cretaceous)** Poorly exposed, dark-gray to light-brown, weakly indurated silty mudstone interlayered with thin-bedded, massive micrite. Pervasive, fracture-controlled, red-brown iron staining is common. This member has yielded abundant vertebrate dinosaur fossils (Bonde et al., 2015). Poorly exposed; forms a subdued saddle between the underlying and overlying rock units. Contact with overlying Knc<sub>4</sub> is not observable in the field. ~105 meters thick.

**Knc<sub>2</sub> Newark Canyon Formation member 2 (Early Cretaceous)** Light-brown to tan, fine- to medium-grained, well-bedded, horizontally to trough and planar cross-bedded sandstone. Interbeds of lensoidal massive pebble conglomerate and trough cross-bedded pebbly-sandstone are also common. Ripples are also well preserved in the fine- to medium-grained sandstone intervals. Exhibits a gradational contact with the overlying Knc<sub>3</sub>. Forms ledges and thin ridges. ~110 meters thick.

**Knc<sub>1</sub> Newark Canyon Formation member 1 (Early Cretaceous)** Tan to brown, locally red-brown weathering, massive to trough cross-stratified, pebble clast-supported conglomerate with abundant interstitial tan to buff, medium- to coarse-grained, planar cross-bedded to normally graded lenticular sandstone. The base of this member is predominately massive to crudely bedded conglomerate, but grades upward into cross-stratified sandstone. Gray and black chert are the dominant pebble clast lithology, while mudstone clasts at the base are less abundant, though unique to this member. U-Pb geochronology from detrital zircons yielded a maximum depositional age of  $130.6 \pm 2.6$  Ma (Di Fiori et al., 2021). Forms ledges and ridges. Gradational contact with Knc<sub>2</sub> above, and angular unconformity with unit Mdp below. ~105 meters thick.

## Paleozoic Rocks

**Mdp Diamond Peak Formation (Upper Mississippian)** Brown, tan, to dark-yellow, medium- to coarse-grained, well-bedded, massive to cross-stratified sandstone. Interstitial gray to gray-green silty mudstone with lenses of tan to brown medium-grained sandstone are common. Chert pebble to cobble conglomerate is the dominant lithology of the prominent ridge in the center of the map area. Locally contains pale-yellow to gray, medium- to coarse-grained sandstone interbeds containing carbonate grains with lesser abundances of chert and quartz grains. Thin, lensoidal limestone beds are locally observed. Typically forms subdued topography, including benches and terraces. Locally altered to jasperoid breccia. Minimum thickness estimated at ~1,000 meters.

**Ddg Devils Gate Limestone (Upper to Middle Devonian)** Light-gray to brown-gray, fine-grained, massive limestone. Contains diagnostic spheroidal stromatoporoids and *Amphipora*. Outcrops exhibit pervasive fracturing and internal deformation. Forms large, steep cliffs and bluffs and erodes as large, angular blocks. At least ~450 meters thick.

**Dox Oxyoke Canyon Sandstone (Middle Devonian)** Light-gray, brown to white, medium- to coarse-grained, massive to cross-stratified, dolomitic quartz arenite with common intercalated horizons of white quartzite. Quartz grains are generally subrounded to subangular and are moderately to well-sorted. Forms diagnostic white to brown-gray hilltops, steep ledges and bluffs. ~110 meters thick.

**Dbp Beacon Peak Dolomite (Lower Devonian)** Light-gray to tan, well-bedded, fine-crystalline dolostone. Exhibits interstitial, cm-scale horizons of white to cream-colored dolostone. Much of the dolostone has 10–50% fine- to medium-grained sand. Fracture-controlled, red-brown, siliceous stringers are abundant. Pervasive tectonic breccia is common in outcrop. ~90 meters minimum thickness.

**Slm Lone Mountain Dolomite (Upper Silurian)** Light-gray to buff, thick-bedded dolostone. Generally coarse-crystalline with diagnostic coarse saccharoidal weathering texture. Often pervasively silicified and brecciated. Not exposed in map area; shown in cross section only. A thickness of ~500 meters is estimated from exposures to the north and from the descriptions of Nolan (1956).

**Ou Ordovician rocks undivided (Ordovician)** Shown in cross section only; not exposed at surface within the map boundary.

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